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ABSTRACT

Acoustic studies have shown that phonetic context can have substantial effects on the cues associated with a given speech sound. The present study investigates whether or not modifications in the acoustic correlates of initial stops and fricatives due to the following vowel can affect phonemic decision processes. In the first of two experiments, C-V syllables comprised of a stop plus a vowel were paired and presented to 36 first-grade subjects in a discrimination task; in the second experiment, fricatives were involved instead of stops. The results for Experiment I showed that subjects discriminated the stops significantly better in long vowel contexts than in short vowel contexts. Results for Experiment II showed that discriminations of place contrasts involving /s/ or /z/ as well as the homorganic voicing contrasts were not subject to differential vowel effects. Discrimination of /f/ from voiceless /th/ and /v/ from voiced /th/, however, were significantly better in back vowel contexts than in front vowel contexts. Discriminations of /f/ from voiceless /th/ and /v/ from voiced /th/ were found to be significantly more difficult than the discriminations of the other fricative contrasts. Results show that effects of coarticulation affect discrimination probabilities. These findings question theories of one-to-one correspondence between the acoustic segment and the sound perceived. (Author/AMM)

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THE EFFECT OF CONTEXTUAL INFLUENCE ON CHILDREN'S DISCRIMINATION OF INITIAL CONSONANTS

Report from the Project on Basic Pre-Reading Skills: Identification and Improvement

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The Wisconsin Research and Development Center for Cognitive Learning focuses on contributing to a better understanding of cognitive learning by children and youth and to the improvement of related educational practices. The strategy for research and development is comprehensive. It includes basic research to generate new knowledge about the conditions and processes of learning and about the processes of instruction, and the subsequent development of research-based instructional materials, many of which are designed for use by teachers and others for use by students. These materials are tested and refined in school settings. Throughout these operations behavioral scientists, curriculum experts, academic scholars, and school people interact, insuring that the results of Center activities are based soundly on knowledge of subject matter and cognitive learning and that they are applied to the improvement of educational practice.

This Technical report is from the Basic Pre-Reading Skills: Identification and Improvement Project in Program 1. General objectives of the Program are to generate new knowledge about concept learning and cognitive skills, to synthesize existing knowledge, and to develop educational materials suggested by prior activities. Contributing to these Program objectives, this project's basic goal is to determine the processes by which children aged 4 to 7 learn to read, examining the development of related cognitive and language skills, and to identify the specific reasons why many children fail to learn to read. Later studies will be conducted to find experimental techniques and tests for optimizing the acquisition of skills needed for learning to read. By-products of this research program include methodological innovations in testing paradigms and measurement procedures; the present study is an example.

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Abstract

Acoustic studies have shown that phonetic context can have substantial effects on the cues associated with a given speech sound. The present study investigates whether or not modifications in the acoustic correlates of initial stops and fricatives due to the following vowel can affect phonemic decision processes.

Two experiments were conducted to investigate contextual effects. In experiment I, C-V syllables comprised of a stop plus a vowel were paired and presented to 36 first grade Ss in a discrimination task. An A-B-X paradigm was employed, using a stereo tape recorder with two speakers. Nine minimal place and voicing contrasts involving the stops /p/, /b/, /t/, /d/, /k/, /g/ were presented, each in the context of eight different vowels. Vowels could be grouped into high and low, long and short, and front and non-front for analysis.

Experiment II differed from Experiment I only in that it involved fricatives instead of stops. The six fricatives /f/, /v/, /θ/, /ð/, /s/, /z/ were employed in making up the nine contrasts.

The results for Experiment I showed that Ss discriminated the stops significantly better in long vowel contexts than in short vowel contexts. The discrimination rates for each contrast, collapsed over all vowels, did not differ from one another.

For Experiment II, the results indicated that discriminations of place contrasts involving /s/ or /z/ as well as the homorganic voicing contrasts were not subject to differential vowel effects. Discrimination of /f/ from /θ/ and /v/ from /ð/, however, were significantly better in back vowel contexts than in front vowel contexts. Discriminations of /f/ from /θ/ and /v/ from /ð/ were found to be significantly more difficult than the discriminations of the other fricative contrasts.

The results show that effects of coarticulation do affect discrimination probabilities. These findings call into question theories that propose any one-to-one correspondence between the acoustic segment and the sound perceived.

Chapter I

INTRODUCTION

Experimental phoneticians have devised a number of strategies to determine the cues in the acoustic signal on which the listener relies for phoneme recognition. A factor which most of these strategies have in common is the identification of isolated nonsense syllables. This forces the listener to make his response to the physical stimulus alone. Semantic, syntactic, and suprasegmental clues are eliminated. An increase in errors can be induced by various methods of signal attenuation, masking, or filtering.

But responses elicited in noise or under conditions of filtering have inherent drawbacks, since may of the important questions concerning phoneme recognition relate to normal processing. In the present study, an attempt is made to investigate some of the variables related to phonemic decision processes by studying children's performance on a consonant discrimination task. Specifically, the purpose of the study is to ascertain the effects of varying the vowel on the child's ability to discriminate minimal consonant contrasts.

The acoustic correlates of consonant production are modified due to the influence of adjacent sound segments. This has been documented by several acoustic studies (e.g., see Öhman, 1963; 1966). Thus, the acoustic correlates of any single consonant are subject to wide variation.

Furthermore, it has been shown thst the cues which lead the listener to a decision about a single phoneme are provided by several successive segments in the acoustic signal. (For a thorough review of the studies related to this question, see Kozhevnikov and Chistovich (1965)). On the basis of this finding, several investigators have concluded that the minimal acoustic unit by which phonemic decisions are made is the syllable (Kozhevnikov and Chistovich, 1965; Lyublinskaya, 1966; Liberman, Cooper, Shankweiler, and Studdert-Kennedy, 1967; Bondarko, 1969).

On the other hand, the authors of distinctive feature theory, while aware of the contextual modification of phoneme cues, did not feel compelled to propose a decision unit larger than the sound segment itself (Halle, 1956; Jakobson and Halle, 1956). These investigators have proposed that each phoneme is represented by a unique bundle of features, which serve to distinguish a given phoneme from all others. The features which specify a phoneme are present in the signal in whatever context the phoneme occurs, and it is on the basis of these features that a phonemic decision is made.

Strong objections have been raised to this aspect of the theory. Fry (1956) points out that if distinctive feature theory actually proposes a one-to-one relationship between the acoustic segment and the phoneme perceived, then the theory is difficult to reconcile with experimental results which indicate the diverse acoustic clues which lead the listener to the same phonemic decision (p. 170). Bush (1964) conducted an acoustic study in which she tested two of the feature oppositions and found that under the influence of certain contexts the oppositions were neutralized or even reversed. This criticism strikes at the proposed invariance of the features.

Bush saw that the authors of the theory were aware of the wide variations that occur in the acoustic correlates of a phoneme because of context. However, in her words, "Their assumption is that all such modifications lie well within the acoustic specification of the distinctive features and the distinctive feature specification of the phoneme (Jakobson and Halle, 1956; Lotz, 1950)." It is important to note that Bush did not feel that her results justify any rejection of distinctive feature theory. She merely felt that the theory needed to be reconciled with her findings.

Recently an attempt was made to reconcile distinctive feature theory with the comments of Fry and the findings of Bush. Bondarko (1969) felt that the theory designating the syllable as the minimal decision unit was correct, and, at the same time, that distinctive feature theory is "without doubt the most economic and systematic description of phonemes. . . .(p. 1)" Thus, he proposed that the realization of the distinctive features be specified in terms of the whole syllable. He based this proposal on the fact that it is precisely the coarticulation of sounds in the syllable that determine the nature of the allophone realized.

However helpful the acoustic and articulatory research can be in refining a theory like that concerned with distinctive features. The theory also relates to perception. It seems imperative to show that the acoustic effects of coarticulation do, in fact, affect phonemic decision processing.

Thus, this study undertakes to show that the child's performance on a consonant discrimination task will be differentially affected by the phonetic context in which the consonant contrast is presented. Since it has been shown that the effect of phonetic environment on the acoustic parameters associated with a given consonant can be substantial, it should be the case that certain environments will have a more favorable effect on the phonemic decision than other environments.

Chapter II

BACKGROUND OF THE PROBLEM

ACOUSTIC PROPERTIES OF STOPS AND FRICATIVES IN CV SYLLABLES

In this section, the acoustic cues related to the discrimination of one stop from another and one fricative from another in CV syllables will be discussed on the basis of research previously reported in the literature. Wherever possible, any influence which varying vowel context may have on these cues will be considered. A survey of what is known about the acoustic parameters that come into play in recognition or discrimination tasks permits some general predictions concerning the outcome of the proposed experiments

Stops

Stop or plosive consonant sounds are produced when the articulators close off the airstream at some point in the vocal tract, causing a build-up of pressure behind the closure. The release of the air built up behind the closure causes a transient "burst" of noise which is the result of turbulence in the airstream at the point of release. At the moment in time when the release occurs, the articulators are moving into the configuration appropriate for the next sound segment. These rapid movements of the articulators are reflected in the acoustic signal as frequency shifts of the major resonances and are called transitions. Figure 1 is a stylized acoustic representation of CV syllables, one (a) initiated by a voiced stop and another (b) initiated by a voiceless stop.

The longer duration of noise characteristic of the voiceless plosive represents the burst plus the aspiration which typically is present after the release of this class of stops in American English. The dark line evident throughout the closure duration of the voiced stop represents the feature of voicing which has its onset typically during the closure of this class of stops.

English stops are distinguished according to the point in the vocal tract where closure occurs. English speakers produce stops at 3 places of articulation; corresponding voiced and voiceless cognates are present at each place of articulation.

	bilabial	alveolar	velar
voiceless	p	t	k
voiced	b	d	g

<u>Frequency, Intensity, and Durational Characteristics of the NOISE Portion</u>. The burst of noise associated with the release of a particular stop consonant has a major concentration of energy centered in a certain area of the frequency spectrum. English /p/, /t/, and /k/ and their voiced cognates /b/, /d/, /g/ have been the subject of acoustic research with regard to this feature. Halle, Hughes, and Radley (1957) presented the following generalizations about the

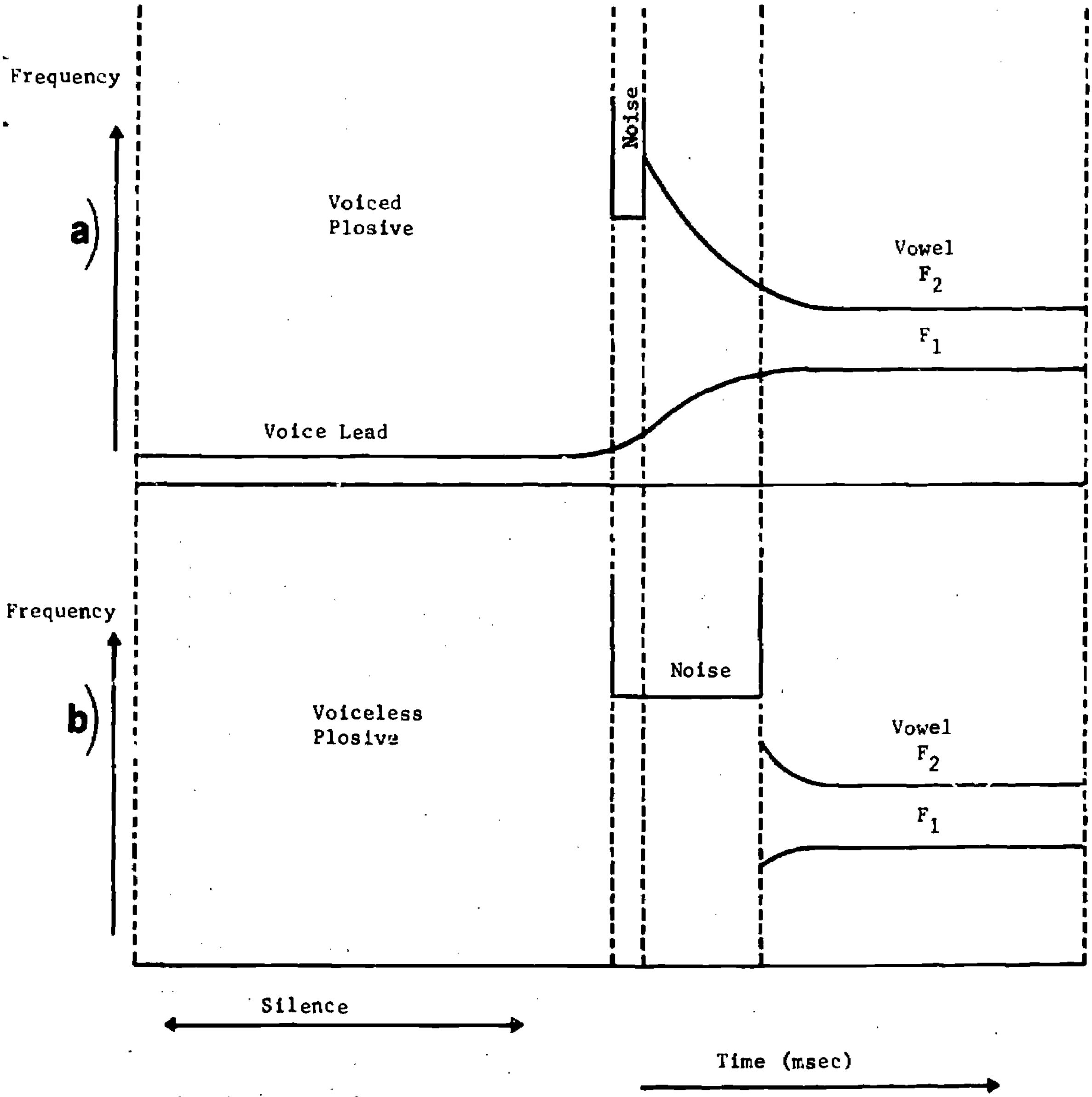

Fig. 1. Sylized acoustic representation of stop + vowel syllables according to the dimensions of frequency characteristics over time. In time, the sequence of articulatory events is as follows: Closure duration, release, transition, vocalic steady state (from Slis and Cohen 1969).

spectral properties of the bursts associated with the three classes of stops:

/p/ and /b/, the bilabial stops, have a primary concentration of energy in the low frequencies (500-1500 cps.).

/t/ and /d/, the alveolar stops, have either a flat spectrum or one in which the higher frequencies (above 4000 cps.) predominate.

/k/ and /g/, the palatal and velar stops, show strong concentrations of energy in the intermediate frequency regions (1500-4000 cps.).

These generalizations were confirmed in research using synthetic speech stimuli by several other investigators (Liberman, Delattre, & Cooper, 1952; Ainsworth, 1968). On the other hand, it has also been shown that a great deal of variation exists in the burst frequency associated with each stop, depending on the following vowel (Liberman, et al., 1952; Fischer-Jørgensen, 1954).

While the burst frequency of a stop can serve as a cue for the identification of that stop, several studies indicate that accurate perceptions of stop sounds can be obtained even without the burst cue present (Liberman, et al., 1952; Halle, et al., 1957; Grimm, 1964). This should not be interpreted as an assertion that the frequency of the noise burst is not utilized in perception, only that it does not seem to be essential. Halle, et al. (1957) showed that, with training, fairly accurate perception of stops can be achieved in response to isolated noise bursts. Minifie, Rudegeair, Milstein, and Vivion (in preparation) spliced out initial transition portions of taped CVC syllables and found that accurate stop recognition was still possible 100% of the time.

Since it is known that the nature of the following vowel does affect the frequency of the burst, and that this in turn may affect discrimination performance, it is appropriate to consider what the outcome of such an effect might be in terms of the present study.

With regard to the place contrasts, /p/ vs. /t/, /p/ vs. /k/, and /t/ vs. /k/, as well as the corresponding contrasts among the voiced stops, differential discrimination rates may be found between vowel environments which render the contrasting bursts more or less similar. A clear example of this might occur with the /p/ vs. /k/ contrast. Before back vowels, the /k/ burst has in common with the /p/ burst a rather low-frequency concentration of energy. Before front vowels, however, as /k/ becomes more palatal rather than velar, the energy concentration associated with the burst occurs at a higher frequency, potentially rendering /k/ less confusable with /p/.

The intensity of the burst is known to vary according to whether the stop is voiced or voiceless (Halle, et al., 1957), but no differential vowel effects are predicted on the basis of this finding, at least not in regard to the homorganic voicing contrasts. It is possible that certain vowels may influence the intensity levels of consonantal bursts within voiced and voiceless classes, thus creating varying intensity differences among the place contrasts. Wang and Fillmore (1961) hypothesized that they would find better consonant recognition when the consonants were adjacent to low vowels, since high vowels have smaller amplitude than low vowels[1] (Lehiste and Peterson, 1959). Their investigation confirmed their hypothesis, although no statistical confirmation was provided.

Duration of the noise portion of CV syllables initiated by stops differentiates the set of voiceless stops from the set of voiced stops (Fischer-Jørgensen, 1954; Vieregge, 1966; Slis & Cohen, 1969). Whether or not different vowel environments affect duration within voiced and voiceless classes is not clear from the research literature. The stimulus tapes in the present study will afford an opportunity to measure for noise duration differences by vowel context as well as an opportunity to ascertain whether or not these potential differences affect performance.

Direction and Extent of the Transition from the Consonant into the Vowel. That the transition from the consonant into the vowel is an important cue to stop sound recognition was discovered early in studies dealing with consonant perception, and especially by a series of experiments conducted by researchers at Haskins Laboratories (Cooper, Delattre, Liberman, Borst & Gerstman, 1952; Liberman, Delattre, Cooper, & Gerstman, 1954; Delattre, Liberman, & Cooper, 1955). These researchers were able to show in synthetic speech experiments that isolated transition plus vowel stimuli were sufficient in themselves to lead to accurate stop identification and they concluded that the

[1]This finding has been disputed by Sharf (1966) who found no consistent intensity differences associated with high and low vowels.

transition was the cue that led the listener to identify the place of articulation of the stop sound in question. If indeed the transition is the primary cue in stop recognition,[2] it would seem to play a crucial role in stop sound confusions. Two contrasting stop sounds should be more confusable in a context where they exhibit highly similar transition patterns than in another context where their transitions are dissimilar.

Consider again the /p/ and /k/ contrast in the context of a back vowel. That the acoustic characteristics of the bursts associated with these sounds have much in common has already been discussed. The transition patterns of these two stops have also been shown to be similar (slightly falling for /k/ vs. neutral for /p/) when the stops precede a back vowel (Halle, et al., 1957). It would seem reasonable, then, to predict that these sounds would be more confusable in a back vowel environment than either sound would be with /t/. Indeed, in the Miller and Nicely (1955) data (at a signal/noise ratio of +12 db and a frequency response of 200-6500 cps.), /pa/ was identified as /ka/ 14% of the time, but never as /ta/. Conversely, /ka/ was identified as /pa/ 8% of the time, while in only 1% of the responses was it identified as /ta/.

A different situation arises in the context of a vowel like /i/. In this case, /k/ is followed by a falling transition, while /p/ is

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[2]Milstein, Minifie, Rudegeair, and Vivion (in preparation) dispute this proposition, since they found that when conflicting burst and transition cues are presented, responses are random with regard to those two parameters.

marked by a sharply rising transition. (Recall that the high frequency component in the noise burst associated with /k/ becomes even higher preceding a front vowel.) From this, it seems logical to conclude that the confusion probabilities among stop sounds can be shown to be a function of phonetic environment.

Duration of the Vocalic Portion. Ample evidence can be found in the literature that vowels have differential intrinsic durations (Peterson & Lehiste, 1960; Lehiste & Peterson, 1961; House, 1961; Lehiste, 1964). It may be that a longer vocalic portion provides a more substantial cue for the identification of the preceding consonant. The longer vocalic portion may provide a longer transition and consequently a stronger cue. The difficulties of defining and measuring transitions from consonant to vowel are well known to experimental phoneticians (Halle, et al., 1957, p. 113). Thus, the literature offers little evidence for or against a hypothesis that transition duration is directly proportional to vowel duration. Lehiste and Peterson (1961) attempted to measure the initial transitions in CVC syllables which combined all initial English consonants with 15 vowels and diphthongs. Their data, in general, serve to confirm that longer vowels yield longer transitions.

In any case, the duration of the vocalic portion of the CV syllable may be crucial with regard to the decision time it affords the listener. If the relevant cues for consonant recognition are present for a longer duration, recognition may well be facilitated.

Voicing and the Moment of Voice Onset. The parameters associated with voicing are only relevant in distinguishing contrasts across voiced and voiceless classes. Voicing in descriptive terms is defined as vocal chord vibration, but acoustic research has refined this definition and it has been shown that the moment in time of the onset of voice serves to distinguish voiced from voiceless sounds (Halle, et al., 1957; Lisker & Abramson, 1965; Slis & Cohen, 1969). Whether or not the onset of voicing within voiced and voiceless classes varied with vowel environment is unknown. There is nothing in the literature, nor is there any plausible reason to suggest that this parameter should have any relevance for discriminating place contrasts.

Other possible cues in discriminating voicing contrasts have been mentioned earlier. The duration of the noise portion distinguishes voiced and voiceless classes, as do sound intensity levels, the voiced class being consistently shorter and less intense. Again it is not clear whether varying vowel environments differentially affect these parameters between homorganic voiced and voiceless pairs. If they do, it is expected that discrimination will be facilitated when differences are emphasized.

Miller and Nicely (1955) studied perceptual confusions of CV syllables presented in noise. They observed fewer confusions on the voicing dimension than on the place dimension. They concluded that voicing is a stronger cue than place in perceptual behavior. If this is true, the homorganic voicing contrasts should be easier to discriminate in the present study. There are clearly several strong acoustic differences between the voiced and voiceless classes that lend support to such a prediction.

Summary. Acoustic cues which interact to aid the listener in discriminating one stop from another have been discussed. Certain of these parameters are known to be affected by vowel environment--primarily the burst frequency and the direction and extent of the second formant transition into the vowel. The variation induced by the vowel may render consonant contrasts more or less discriminable, particularly in the case of place contrasts. Thus, one might speak of "optimal" environments for the discrimination of the contrast pair--the optimal environment being the one in which differences are emphasized.

Different vowel environments may not differentially affect the homorganic voicing contrasts since burst and transition information is equally similar for the members of the contrast pair, given the same vowel environment for each member. Furthermore, earlier work indicates that the voicing feature is a stronger cue than any other (Miller & Nicely, 1955). In terms of a discrimination task, then, voicing contrasts should be easier than place contrasts.

Fricatives

Fricatives differ from stops in the manner in which they are produced. Complete closure is not characteristic of fricatives. Intra-oral pressure is built up behind a constriction in the vocal tract, but it is in a constant state of turbulent release throughout the duration of fricative production. Voiceless fricatives have a single sound source--that at the point of major constriction where the air turbulence is generated, while voiced fricatives have a double sound source--one at the level of the glottis and one at the point of constriction in the vocal tract.

The acoustic result of generating air turbulence in the vocal tract is quasi-random noise. Hence, fricatives are essentially durations of noise over a broad area of the frequency spectrum. Fricatives at different points of articulation are distinguished by their frequency characteristics, sound intensity levels, and durations, as well as by transitions to (or from) adjacent vowels (Tolhurst, 1949; Hughes & Halle, 1955; Harris, 1958; Strevens, 1960; Delattre, Liberman, & Cooper, 1962). Figure 2 is a stylized acoustic representation of CV syllables, one (a) initiated by a voiceless fricative and another (b) initiated by a voiced fricative.

In the present study, concern is focused on only minimal fricative contrasts along the dimensions of place of articulation and voicing. The literature will be surveyed in order to establish some general predictions about how varying vowel context may effect the cues available to the listener in syllables composed of fricative plus vowel. The voiced and voiceless friactives of English can be classified according to their place of production.

	Labio-dental	inter-dental	alveolar	palatal	glottal
voiceless	f	θ	s	s	h
voiced	v	ð	z	z	

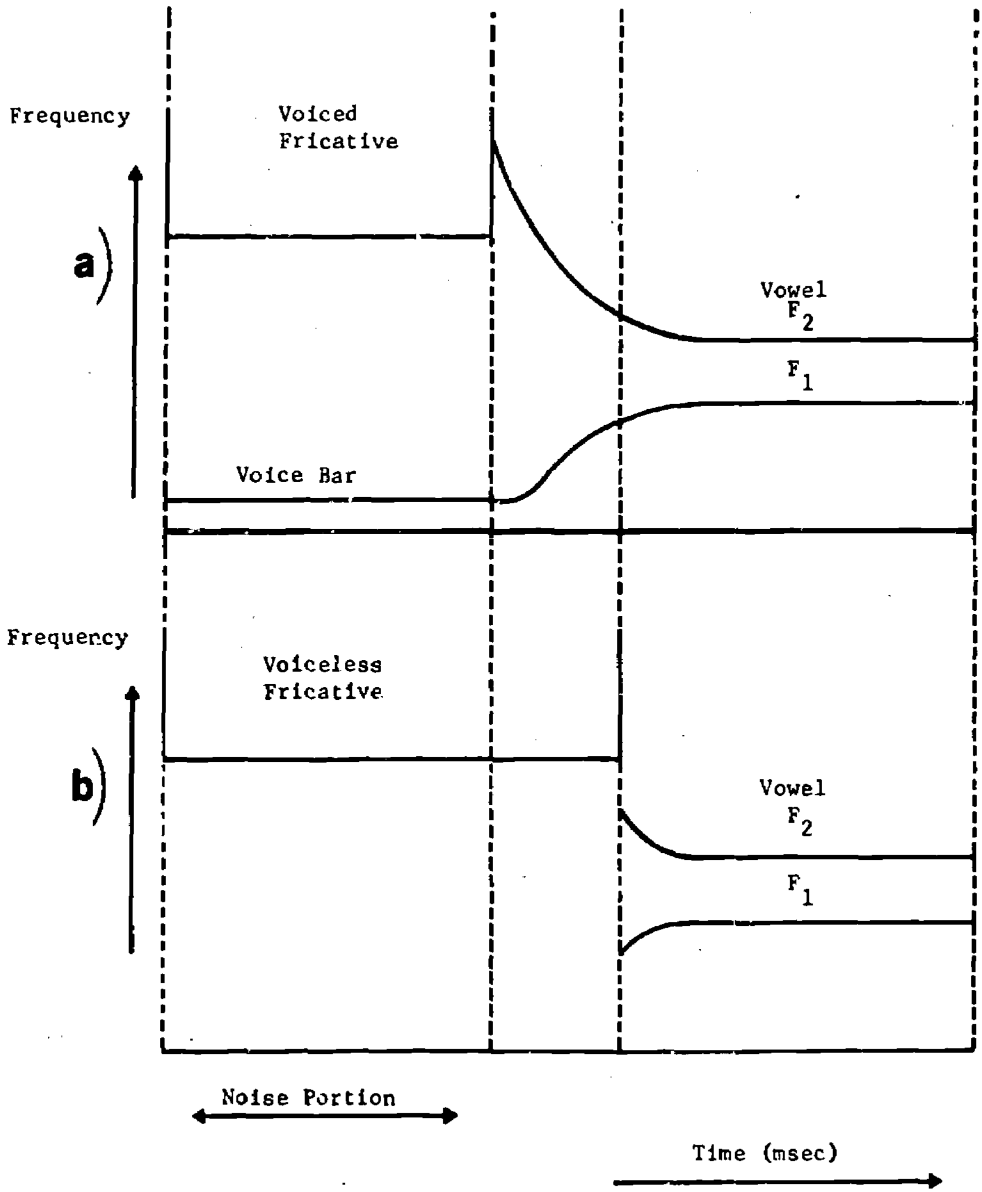

Fig.2. Stylized acoustic representation of fricative + vowel syllables along the dimensions of frequency characteristics over time. In time, the sequence of articulatory events is as follows: Turbulent noise generated at point of construction, transition, vocalic steady state (from Slis and Cohen 1969).

For reasons to be made clear later /s/, /z/, and /h/ are irrelevant in the ensuing discussion.

Frequency, Intensity, and Duration of the Noise Portion. Acoustic studies reveal differences in the frequency characteristics of English fricatives which may enable the listener to distinguish among them. Acoustic measures by Abbs and Minifie (1969) on fricatives in VC and CV syllables indicated that /s/ and /z/ have major resonances at the high end of the frequency spectrum, while /f/, /v/, /θ/, /ð/ have major resonances significantly lower. These results are in agreement with those of Strevens (1960), who found that /s/ had higher major resonances than /f/ and /θ/, while /f/ and /θ/ show very similar frequency characteristics.

The range of energy spread around the major resonances has also been measured and /s/ and /z/ were found to be characterized by much shorter ranges of energy than /f/, /v/, /θ/, /ð/ (Abbs & Minifie, 1969; Strevens, 1960).

Intensity measures have also shown differences among the fricatives. Several studies have shown /s/ and /z/ to be significantly more intense than the other fricatives (Denes and Pinson, 1963; Abbs & Minifie, 1969). There is disagreement in the literature regarding the intensity levels characteristic of the voiced class vs. the voiceless class of fricatives. Abbs and Minifie (1969) found no differences between voiced and unvoiced fricatives, while Sacia and Beck (1926) as well as Fletcher (1953) have reported that such differences exist.

Abbs and Minifie (1969) further report two differential factors concerning the duration of the noise portion in CV syllables initiated by a fricative. First, they report that the voiceless fricatives are associated, in general, with longer durations of noise than their voiced counterparts. This is hypothetically supported by Slis and Cogen (1969) as is apparent in the stylized representation of fricative plus vowel syllables presented in Figure 2. Secondly, Abbs and Minifie report that /s/ is characterized by a longer noise duration than any of the other fricatives, while /v/ and /ð/ are significantly shorter than any of the other fricatives.

Different vowel environments will affect any of the cues discussed so far in this section. But there seems to be no reason to expect that the fricatives will be affected differentially by differing vowel contexts--at least along these dimensions related to the noise portion. Although the possibility is present, there is no evidence to support it.

Direction and Extent of the Second Formant Transition into the Vowel. As with the stops, the second formant transition from a fricative into the vowel has been found to be an important cue in identifying the place of articulation (Delattre, et al., 1962). Harris (1958) has shown, however, that the noise portions associated with /s/ and /š/ are such powerful cues that transitions only seem to assume importance as cues in identifying /f/, /v/, /θ/, /ð/.

Based on these findings, the situation should be such in a discrimination task that /s/ would be rather easy to discriminate from any other voiceless fricative despite vowel context. The discrimination of /s/ from its homorganic voiced counterpart is a separate matter. Conversely, discriminations between /f/ and /θ/, /v/ and /ð/ should be more difficult and, perhaps, susceptible to cue variations caused by different vowel contexts. Recall that /f/ and /θ/ (as well as their voiced cognates) are characterized by very similar frequency characteristics, which at the same time are of extremely low intensity (Strevens, 1960).

Indeed, if a survey is taken of experimental work where discrimination tasks are used, /f/ vs. /θ/ and /v/ vs. /ð/ discriminations show unusually high error rates when compared to both stop and any other fricative discriminations (Travis & Rasmus, 1931; Templin, 1943; Tikofsky & McInish, 1968; Abbs & Minifie, 1969; Rudegeair & Kamil, 1970).

It is not surprising then that the transition to the vowel should play an important role in the labio-dental vs. interdental fricative discriminations. Nor would it be surprising to find differential vowel effects regulating the ease with which this discrimination can be made. Since vowels clearly affect transition patterns, some vowels might prove to be optimal contexts in terms of emphasizing differences between the fricatives at issue.

Duration of the Vocalic Portion. Intrinsic vowel duration has been discussed and the relevant literature cited in the section dealing with stops. The same arguments presented there apply to fricatives.

If longer transitions are associated with longer vowels, differential discrimination rates may be found associated with vowel length differences. It is worth mentioning again that any parameter that might emphasize acoustic differences between the members of a contrast pair is capable of yielding differential effects.

Voicing and the Moment of Voice Onset. As with stops, the moment of voice onset distinguishes the class of voiced from unvoiced fricatives. Varying vowel environment is not known to affect this feature of the acoustic signal. Other correlates of voicing have been mentioned in connection with the appraisal of the noise portion of a fricative plus vowel syllable. The voiced fricatives have a shorter noise intensity and perhaps the noise is less intense than the noise associated with the unvoiced fricatives. No reason to expect effects from varying vowel environment is evident in the literature with regard to the homorganic voicing contrasts.

Summary. Acoustic cues associated with CV syllables involving fricative consonants have been discussed. With regard to the place contrasts, it was shown that /s/ has a distinctive noise spectrum and should be easily discriminable from any other fricative regardless of context. On the other hand /f/ and /θ/ and their voiced cognates have highly confusable noise portions and discriminations between these sounds should be optimal in vowel environments where transition differences are emphasized.

EARLIER STUDIES OF THE PERCEPTUAL EFFECTS OF VARYING CONTEXTS

The hypothesis that different vowel contexts may have differential effects on the ease with which a consonant is recognized has been investigated in several earlier studies. Sherman (1952) selected 6 voiceless consonants, /θ, f, s, š, t, p/, and 3 vowels, /æ, ʊ, i/, from which she could construct CV and VC combinations where the consonant had either a "large effect" or a "small effect" on the acoustic structure of the second formant transition between the consonant and adjacent vowel. Sherman reasoned that, in the case where the consonant has a large effect on the second formant of the vowel, recognition of the consonant would be facilitated.

By presenting six listeners with thirteen trials of all possible CV and VC combinations, uttered by three different speakers at ten levels of attenuation, she obtained 234 identifications of each syllable at each attenuation level. Sherman's analysis, in general, showed unsystematic results. However, significant differences were obtained between recognitiion of certain consonants in conjunction with a particular vowel and the same consonant in conjunction with some other vowel (e.g., recognition of /pʊ/ was significantly better than recognition of /pi/). These differences were not always in accord with Sherman's original predictions which proposed that better recognition would result with the consonants having the "large effect" on F_2 of the vowel. Table 1 shows the relationship between what was predicted and what the data showed. In the left-hand column is presented the predicted outcome on the basis of the "large effect < small effect" formula. In the column on the right, the corresponding actual results are presented; these results represent all significantly different syllable pairs (in terms of recognition) found in Sherman's data.

Table 1

Comparison of Predicted Results versus Actual Results in Sherman Study of Effects of Contextual Influence on Consonant Recognition

Sherman would predict that recognition of:	Results showed that recognition of:
iθ > æθ	iθ > æθ (speakers 123)
pi > pʊ	pi < pʊ (speakers 123)
ip > ʊp	ip < ʊp (speakers 123)
tʊ > tæ	tʊ < tæ (speaker 1)
ʊt > æt	ʊt > æt (speakers 1+3)
si > sæ	si < sæ (speaker 3)
is > æs	is < æs (speaker 1)
is > æs	is > æs (speaker 3)
šʊ > ši	šʊ > ši (speakers 123)
ʊš > iš	ʊš > iš (speakers 123)

It can be concluded, as Sherman did in fact conclude, that, in the main, the data support the hypothesis that percent recognition of a given consonant changes with variations in the vowel. However, the degree of influence on F_2 of the vowel does not account for the results since many of Sherman's predictions do not hold up at all and several are contradicted.

Wang and Fillmore (1961) also proposed to evaluate the effect of the interaction of the consonant and vowel on the perception of the consonant. Only the influence of three specific cues were under investigation in this study: vowel amplitude, degree of second formant bend, and nasalization.

Citing Peterson and Lehiste (1959), Wang and Fillmore noted that high vowels have smaller amplitudes than low vowels. This is based on the finding that the intensity of vowels increases proportionally with the degree of mouth opening associated with vowel production (Fairbanks, House, & Stevens, 1950; Black,1949; Lehiste and Peterson, 1959). Thus, the investigators asserted that consonant perception would be facilitated in CVC syllables containing low vowels.

Arguing that since labial consonants before /i/ and alveolar consonants before /u/ cause the greatest bend in the second formant transition to the vowel, Wang and Fillmore predicted that perception of these consonants before these vowels would be easier than perception of the same consonants in different vowel environments.

Finally, since nasal consonants cause the following vowel to be slightly nasalized, these investigators felt that the presence of this positive secondary cue should facilitate perception of the nasal consonants.

In this study, nine consonants, /p, t, k, b, d, g, m, n, ŋ/, and five vowels, /i, ɛ, a, ɔ, u/, were selected and arranged in all possible CVC combinations, yielding 405 (9 x 5 x 9) stimulus items. These were randomized and recorded on tape for presentation to ten phonetically trained transcribers. Masking noise was used to induce misperceptions; a signal to noise ratio of 6 db was obtained by means of a mixer. Frequencies below 200 cps and above 6500 cps in both the noise and the test tape were attenuated by filtering.

Results showed that responses on final consonants were nearly random and only results on initial consonants were reported. Data on these initial consonants were taken only from items where a correct identification of the vowel was made. Correct identification of vowels was high (c. 90%). The results concerning the specific cues under consideration were as follows:

a) When all consonant data were pooled, the data showed more recognition errors on consonants before high vowels than before non-high vowels. Thus, it was concluded that the higher the intrinsic vowel amplitude, the better the consonant perception. The original hypothesis was thereby supported.

b) When the consonants are pooled according to place of articulation, the data showed that in response to bilabials before [i] and alveolars before [u], error rates were "impressively" lower than other scores for the same vowels. Thus, it was concluded that the degree of bend in F_2 is positively correlated with the identifiability of the associated consonant.

Chapter III

METHOD

To test the question raised in the previous chapter, two experiments were planned--one to test stop sound discriminations, the other involving fricatives.

Experiment I: Initial Stop Discrimination

Subjects. Thirty-six children in first grade served as Ss. All were attending a public school in Madison, Wisconsin. Their ages ranged from 6 years, 7 months, to 7 years, 7 months. Before participating in the present study, all Ss were given a hearing screening test. None of the Ss showed a hearing loss.

Stimulus items. In Experiment I, the series of six English stop consonants was studied in initial position in combination with eight vowels. Stimulus items were prepared by combining each of nine consonant contrasts (e.g., /p/ vs. /t/) with eight different vowels (yielding e.g., /pa/ vs. /ta/). Stimulus tapes were recorded by the experimenter at the recording studio of radio station WHA in Madison, Wisconsin. Table 2 presents the consonant x vowel matrix which yields the stimulus items.

The first three consonant contrasts consisted of voiceless stops which contrast with regard to place of articulation. The next three contrasts involved voiced stops which contrast with regard to place of

c) When the consonants were pooled according to manner of articulation, the data showed that except before [u] the nasal consonants exhibited the lowest error rates. Thus, it was concluded that nasalization in the vowel is a positive influence in consonant identification.

Both the Sherman and the Wang and Fillmore studies used adult subjects who were asked to identify monosyllables presented either in noise or under conditions of signal attenuation. Both studies reinforce the notion that consonant recognition scores can be affected by varying vowel context.

articulation; the final three contrasts consisted of homorganic stops which contrasted with regard to voicing (i.e., one is voiced and one is voiceless).

Peterson and Lehiste (1960) found that vowels could be classified according to their intrinsic duration. Thus, vowels were chosen so that four intrinsically "long" vowels, /i/, /æ/, /a/, /u/, and four intrinsically short vowels, /ɪ/, /ɛ/, /ə/, /ʊ/, that correspond with regard to place of production, are employed. Furthermore, these vowels allow comparisons between four front vowels, /i/, /ɪ/, /æ/, /ə/, and four back vowels, /a/, /ə/, /u/, /ʊ/, as well as comparisons between four high vowels, /i/, /ɪ/, /u/, /ʊ/. and four low vowels, /æ/, /ɛ/, /a/, /ə/.

TABLE 2

Consonant Contrast-Vowel Matrix Which Yields the Stimulus Items

Vowels	Contrast Types								
	Voiceless Place			Voiced Place			Voicing		
	1. p-t	2. p-k	3. t-k	1. b-d	2. b-g	3. d-g	1. p-b	2. t-d	3. k-g
i	pi-ti	pi-ki	ti-ki	bi-di	bi-gi	di-gi	pi-bi	ti-di	ki-gi
æ	pæ-tæ	pæ-kæ	tæ-kæ	bæ-dæ	bæ-gæ	dæ-gæ	pæ-bæ	tæ-dæ	kæ-gæ
a	pa-ta	pa-ka	ta-ka	ba-da	ba-ga	da-ga	pa-ba	ta-da	ka-ga
u	pu-tu	pu-ku	tu-ku	bu-du	bu-gu	du-gu	pu-bu	tu-du	ku-gu
ɪ	pɪ-tɪ	pɪ-kɪ	tɪ-kɪ	bɪ-dɪ	bɪ-gɪ	dɪ-gɪ	pɪ-bɪ	tɪ-dɪ	kɪ-gɪ
ɛ	pɛ-tɛ	pɛ-kɛ	tɛ-kɛ	bɛ-dɛ	bɛ-gɛ	dɛ-gɛ	pɛ-bɛ	tɛ-dɛ	kɛ-gɛ
ə	pə-tə	pə-kə	tə-kə	bə-də	bə-gə	də-gə	pə-bə	tə-də	kə-gə
ʊ	pʊ-tʊ	pʊ-kʊ	tʊ-kʊ	bʊ-dʊ	bʊ-gʊ	dʊ-gʊ	pʊ-bʊ	tʊ-dʊ	kʊ-gʊ

Task and Procedures. Subjects were given a sound discrimination test wherein each S responded twice to each of the 72 contrasting CV (consonant + vowel) syllables.

An A-B-X paradigm was employed in presenting the stimulus pairs to Ss. Subjects were seated midway between the two speakers (model 1113) of an Ampex stereo tape recorder (model 1160). Figure 3 illustrates the experimental situation. A warning signal (1000 cycle tone) followed by the first member of a contrast pair (item A) was always heard over the left speaker. One second later the second member of the contrast pair (item B) was heard over the right speaker. One second later "who said X" (where X is either A or B) was heard over both speakers. Subjects then had three seconds in which to respond before the warning signal initiated the next trial. Subjects responded by pointing to the appropriate speaker. The experimenter, who was seated behind S at all times, recorded all responses immediately on prepared data sheets.

It has been found that in using an A-B-X paradigm in phonological testing, the A-B-A alternative produces significantly more errors than the A-B-B alternative (Briere, 1966; Rudegeair & Kamil, 1969). Thus, in this study, presentations had to be carefully counter-balanced so that a given contrast occurred equally in A-B-A and A-B-B instances. Since the order of appearance of the members of a given contrast pair might also create a response bias, this, too, was carefully counterbalanced. For this reason, four different

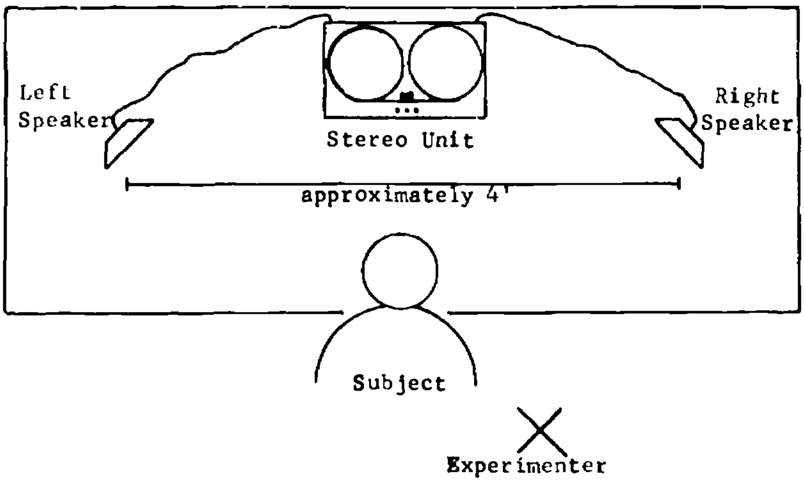

Fig. 3. Schematic diagram of experimental situation. Subject is seated midway between stereo speakers.

sets" of the 72 stimulus items were prepared. Each "set" consisted of three recorded tapes of 24 items per tape, for a total of 12 tapes. Consider the contrast /pa/ - /ta/. Table 3 indicates the form in which it appeared in each of the four sets.

TABLE 3

Example of Counterbalance Design Used With Each Stimulus Pair and Query

	Left Speaker	Right Speaker	Query
Set A	/pa/	/ta/	"Who said /ta/?"
Set B	/pa/	/ta/	"Who said /pa/?"
Set C	/ta/	/pa/	"Who said /ta/?"
Set D	/ta/	/pa/	"Who said /pa/?"

Subjects were tested over seven sessions, one session on each of seven successive school days. For clarity, these days are referred to as Days 0 through 6. Data from Day 0 were disregarded in the analysis. The procedure of repeated testing and of disregarding Day 0 data has been justified in a previous study (Rudegeair and Kamil, 1970). In that study, the only significant improvement in performance occurred between the initial session (Day 0) and the following session (Day 1). It is fair to assume that this decrease in errors is not due to sound discrimination learning, but to _task_ learning. Thus, Day 0, in the present study, serves as Task Training. On Day 0, each _S_ was randomly assigned one of the 12 tapes with the restriction that each tape appear an equal number of times.

On Days 1 through 6, _Ss_ received 6 tapes in counterbalanced order with the restriction that each _S_ received all 72 stimulus items (one "set") on Days 1, 2, 3, and all stimulus pairs again (a different "set") on Days 4, 5, 6. Thus, each subject responded twice to each contrast pair--once during the first three days and once again during the second three days. All stimulus lists appear in the Appendix.

The following restrictions were put on each of the three stimulus lists comprising each "set":

1) the same vowel never appears in two successive items

2) the same consonant contrast never appears in two successive items

3) each vowel appears three times on each list

4) each consonant contrast appears three times in each list except: (since there are nine consonant contrasts and only 24 items per list)

   a) one of the voiceless place contrasts appears only twice on a given list

   b) one of the voiced place contrasts appears only twice on any given list

   c) one of the voicing contrasts appears only twice on any given list

5) each list contains 12 ABA and 12 ABB items.

Design. A five-factor within subject design was employed. Seventy-two observations were made on each subject, and each observation can be classified in terms of the three contrast types (voiceless place contrasts, voiced placed contrasts, and voicing contrasts) with three contrasts nested within each of the three sets (labeled contrast 1, contrast 2, contrast 3). These 9 contrasts appear in combination with two levels of vowel length (long-short), two levels of vowel frontness (front-back), and two levels of vowel height (high-low). Each subject appeared twice in this design for a total of 144 observations per subject.

Experiment II: Initial Fricative Discrimination

In this experiment, the same Ss were subject to the same task and procedures as in experiment I. The only thing that differed was the nature of the consonant contrasts. In this experiment, fricatives were tested instead of stops. Table 6 shows the fricative contrast x vowel matrix which yields the stimulus items.

TABLE 4

Fricative Consonant Contrast-Vowel Matrix Which Yields the Stimulus Items

Vowels	Contrast Types								
	Voiceless Place			Voiced Place			Voicing		
	f-θ	f-s	θ-s	v-ð	v-z	ð-z	f-v	θ-ð	s-z
i	fi-θi	fi-si	θi-si	vi-ði	vi-zi	ði-zi	fi-vi	θi-ði	si-zi
æ	fæ-θæ	fæ-sæ	θæ-sæ	væ-ðæ	væ-zæ	ðæ-zæ	fæ-væ	θæ-ðæ	sæ-zæ
a	fa-θa	fa-sa	θa-sa	va-ða	va-za	ða-za	fa-va	θa-ða	sa-za
u	fu-θu	fu-su	θu-su	vu-ðu	vu-zu	ðu-zu	fu-vu	θu-ðu	su-zu
ɪ	fɪ-θɪ	fɪ-sɪ	θɪ-sɪ	vɪ-ðɪ	vɪ-zɪ	ðɪ-zɪ	fɪ-vɪ	θɪ-ðɪ	sɪ-zɪ
ɛ	fɛ-θɛ	fɛ-sɛ	θɛ-sɛ	vɛ-ðɛ	vɛ-zɛ	ðɛ-zɛ	fɛ-vɛ	θɛ-ðɛ	sɛ-zɛ
ə	fə-θə	fə-sə	θə-sə	və-ðə	və-zə	ðə-zə	fə-və	θə-ðə	sə-zə
ʊ	fʊ-θʊ	fʊ-sʊ	θʊ-sʊ	vʊ-ðʊ	vʊ-zʊ	ðʊ-zʊ	fʊ-vʊ	θʊ-ðʊ	sʊ-zʊ

Chapter IV

RESULTS

MULTIVARIATE ANALYSIS OF ERROR DATA

For each of the two studies, a proportion error score was computed for each S's two responses to each of the 72 consonant pairs. Mean proportion of errors for each stop consonant pair is shown in Table 5; the means for fricative contrasts are shown in Table 6.

For each study, 72 linear contrasts were defined and grouped into 23 sources for a multivariate analysis. These groups of linear contrasts represent all of the main effects and interactions arising from the following within-subjects design: vowel length (2) x vowel frontness (2) x vowel height (2) x contrast type (3) x pair nested within contrast type (3). The null hypothesis for each linear contrast was that the result of the contrast would not differ from zero. The linear contrasts defined for each source became the dependent variables for a multivariate analysis of variance. The multivariate was carried out using Finn's (1968) program. The significance level adopted for the multivariate test for each source was $p < .01$.

TABLE 5

Mean Proportion of Errors for Each Stop Consonant Contrast Pair by Following Vowel

Vowel Context	Contrast Type: Voiceless Place 1. p-t	2. p-k	3. t-k	Voiced Place 1. b-d	2. b-g	3. d-g	Voicing 1. p-b	2. t-d	3. k-g	Mean
i	.04	.04	.10	.10	.05	.11	.07	.07	.10	.075
æ	.14	.14	.05	.07	.14	.14	.10	.08	.08	.101
a	.04	.04	.10	.19	.12	.07	.10	.05	.08	.089
u	.04	.03	.07	.03	.03	.11	.10	.07	.10	.063
ɪ	.10	.10	.12	.07	.08	.15	.11	.07	.18	.109
ɛ	.11	.07	.18	.10	.11	.07	.05	.07	.14	.100
ə	.17	.15	.21	.11	.05	.08	.07	.11	.11	.119
ʊ	.12	.12	.04	.11	.14	.05	.15	.12	.08	.106
Mean	.095	.086	.109	.097	.092	.093	.092	.081	.112	

TABLE 6

Mean Proportion of Errors for Each Fricative Consonant Contrast Pair by Following Vowel

Vowel Context	Contrast Type: Voiceless Place 1. f-ð	2. f-s	3. θ-s	Voiced Place 1. v-ð	2. v-z	3. ð-z	Voicing 1. f-v	2. θ-ð	3. s-z	Mean
i	.44	.05	.11	.37	.02	.04	.15	.18	.05	.159
ɚ	.37	.04	.08	.28	.10	.10	.12	.11	.18	.156
a	.22	.08	.07	.12	.08	.05	.10	.19	.11	.115
u	.19	.10	.04	.11	.07	.02	.14	.12	.15	.105
ɪ	.36	.12	.07	.25	.10	.14	.12	.18	.10	.160
ɛ	.29	.07	.18	.37	.12	.04	.15	.15	.11	.166
ə	.17	.05	.10	.22	.04	.08	.07	.07	.05	.095
ʊ	.26	.08	.05	.24	.07	.05	.15	.14	.18	.137
Mean	.289	.076	.088	.246	.074	.067	.126	.144	.118	

For the post hoc interpretation of the univariate F tests for contrasts associated with a significant multivariate source, the alpha level was scaled down in order to control the error rate for the tests considered as a group. Following a procedure suggested by Miller (1966), the significance level for each univariate F test was set at α/k, where k was the number of linear contrast comprising the source.

Experiment I: Initial Stop Discrimination

For the discrimination task involving initial stops, Table 7 shows the F-ratios for the multivariate test of the equality of mean vectors. Of the 23 sources listed in the table only the length factor showed a significant effect. Figure 4 graphically presents the means for each stop consonant contrast as a function of long and short vowels. Since there are no significant interactions with the vowel length factor, it must be assumed that this is an overall effect. However, the graph (Figure 4) clearly shows an interaction. Contrast type x vowel length interaction is found, in fact, to be of borderline significance, $F(2, 34) = 2.53$, $p < .09$, in the multivariate analysis. The subsequent univariate F test indicates that the effect is due to differential error rates on the voiceless place contrasts, $F(1, 35) = 5.03$, $p < .03$, while there is no significant difference between the error rates for voiced place and voicing contrasts on this dimension, $F(1, 35) = 1.40$, $p < .24$).

TABLE 7

Source Table for the Multivariate Analysis of Variance of Error Data From the Stop Discrimination Task

Source	F	df	Probability
Vowel Length	10.48	1,35	<.002*
Vowel Frontness	.048	1,35	<.82
Vowel Height	2.81	1,35	<.10
Contrast Type	.03	2,34	<.96
Pair Within Contrast Type	.73	6,30	<.62
Length x Frontness	1.29	1,35	<.26
Length x Height	1.97	1,35	<.17
Frontness x Height	.68	1,35	<.41
Length x Frontness x Height	.48	1,35	<.49
Type x Length	2.53	2,34	<.09
Type x Frontness	.04	2,34	<.95
Type x Height	2.77	2,34	<.07
Type x Length x Frontness	1.46	2,34	<.24
Type x Length x Height	1.90	2,34	<.16
Type x Frontness x Height	.40	2,34	<.67
Type x Length x Frontness x Height	2.12	2,34	<.13
Pair x Length	.25	6,30	<.95
Pair x Frontness	1.79	6,30	<.13
Pair x Height	1.01	6,30	<.43
Pair x Length x Frontness	1.39	6,30	<.24
Pair x Length x Height	2.12	6,30	<.08
Pair x Frontness x Height	1.22	6,30	<.31
Pair x Length x Frontness x Height	2.8	6,30	<.03

*Significant at level indicated.

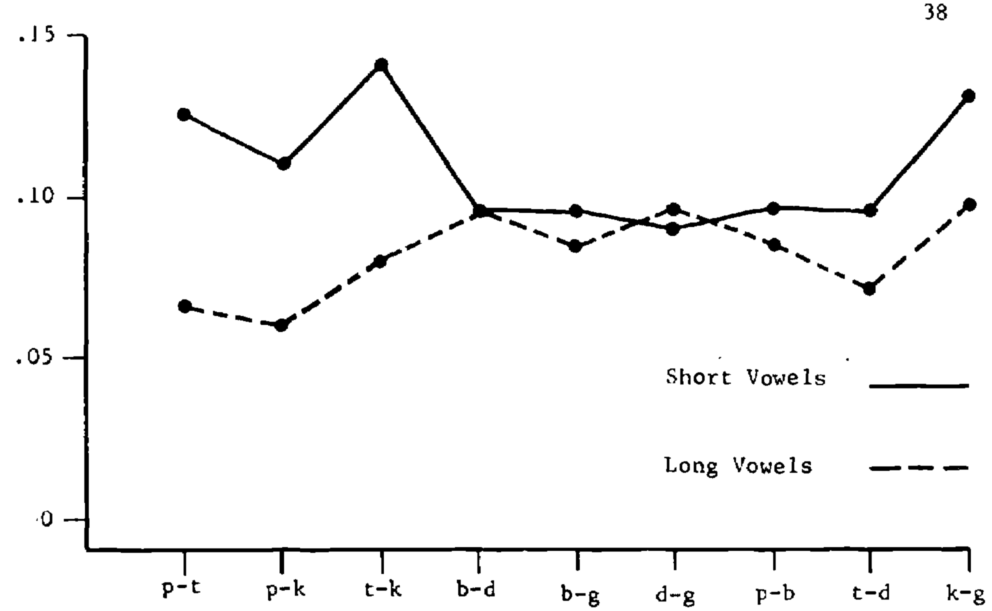

Fig. 4. Mean proportion of errors for 9 stop consonant contrasts as a function of long and short vowels.

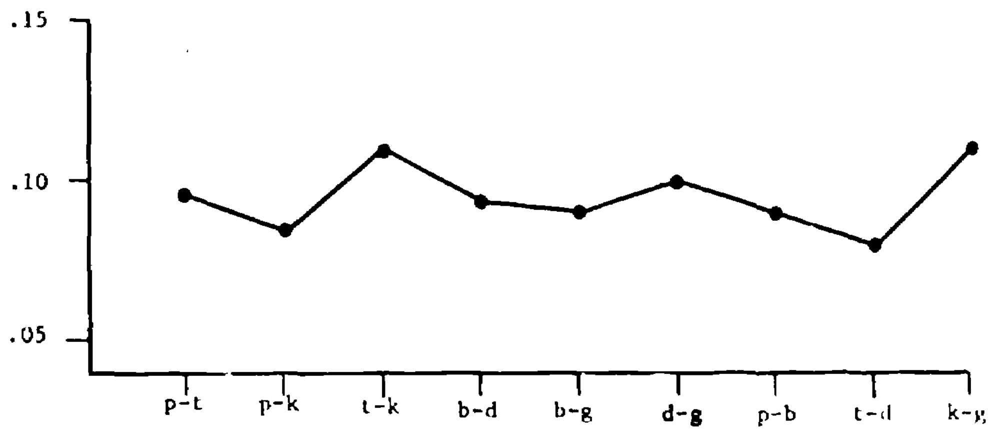

Fig.5. Mean proportion of errors for each of 9 stop consonant contrasts collapsed over all vowels.

Several other results in the analysis are worthy of note. Figure 5 is a display of the mean proportion of errors for each consonant contrast collapsed over all vowel environments. The analysis shows no significant differences among these error rates.

Figure 6 shows the mean proportion of errors for each of 9 consonant contrasts as a function of front vs. back vowels. The analysis indicates that there are no significant differences for any of the contrasts along this dimension. In Figure 7 the mean proportion of errors for each of the 9 contrasts are presented as a function of high and low vowels. The multivariate analysis indicates that the contrast type x vowel height interaction was of borderline significance, $F(2, 34) = 2.77$, $p < .07$. The univariate analysis for this source indicates that error rates for the voiceless place contrasts differ from the voiced place and the voicing contrasts on the vowel height dimension, $F(1, 35) = 3.44$, $p < .07$. The contrast type x vowel height is displayed in Figure 8.

Experiment II: Initial Fricative Discrimination

For the error data from the task involving fricatives, Table 8 shows the F-ratios for the multivariate test of the equality of mean vectors. Three sources were found to have significant F-ratios in this analysis: 1) vowel frontness, 2) pairs within contrast type, and 3) the pairs within contrast type x frontness interaction.

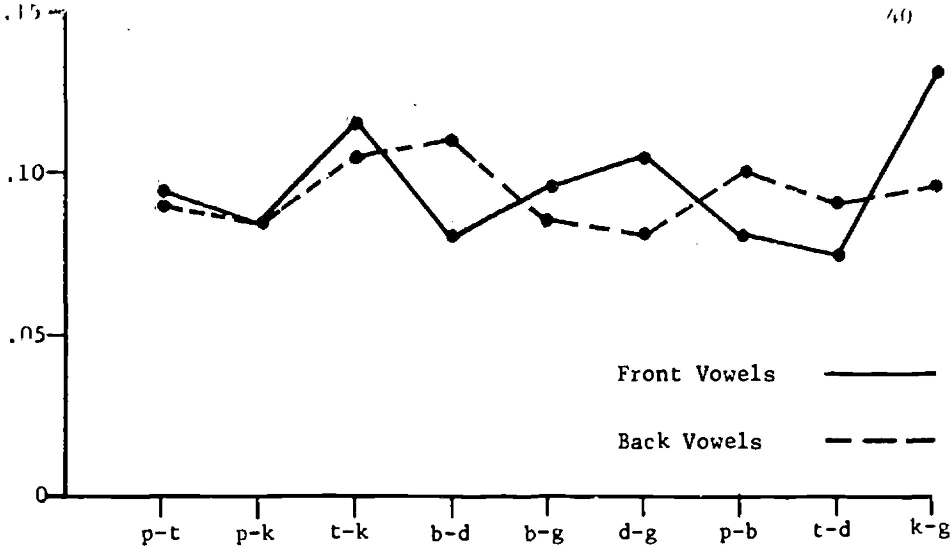

Fig. 6. Mean proportion of errors for 9 stop consonant contrasts as a function of fron and back vowels.

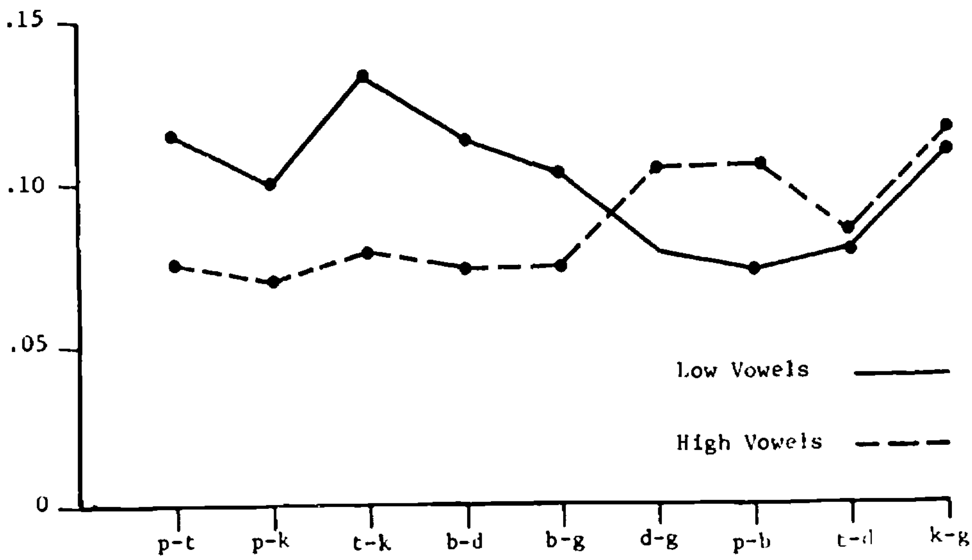

Fig. 7. Mean proportion of errors for 9 stop consonant contrasts as a function of high and low vowels.

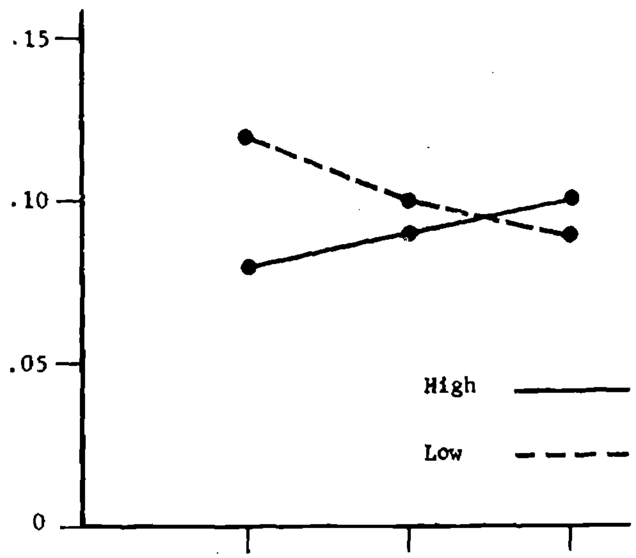

Fig. 8. Mean proportion of errors for 3 contrast types as a function of high and low vowels (from the stop study).

TABLE 8

Source Table for the Multivariate Analysis of Variance of Error Data From the Fricative Discrimination Task

Source	F	df	Probability
Vowel Length	.09	1,35	< .40
Vowel Frontness	24.25	1,35	< .0001*
Vowel Height	.12	1,35	< .49
Contrast Type	1.55	2,34	< .22
Pair Within Contrast Type	24.75	6,30	< .0001*
Length x Frontness	.0000	1,35	<1.00
Lenth x Height	1.08	1,35	< .30
Frontness x Height	.59	1,35	< .44
Length x Frontness x Height	3.17	1,35	< .08
Type x Length	2.40	2,34	< .10
Type x Frontness	3.05	2,34	< .06
Type x Height	1.25	2,34	< .29
Type x Length x Frontness	.93	2,34	< .40
Type x Length x Height	.68	2,34	< .51
Type x Frontness x Height	1.75	2,34	< .18
Type x Length x Frontness x Height	.17	2,34	< .84
Pair x Length	.59	6,30	< .73
Pair x Frontness	3.89	6,30	< .005*
Pair x Height	.85	6,30	< .53
Pair x Length x Frontness	2.09	6,30	< .08
Pair x Length x Height	2.71	6,30	< .03
Pair x Frontness x Height	2.31	6,30	< .06
Pair x Length x Frontness x Height	1.68	6,30	< .16

*Significant at level indicated

Table 9 shows the results of the univariate F tests for each of the linear contrasts comprising the sources which showed significant effects in the multivariate tests. The vowel frontness effect must be reported in conjunction with the pair x vowel frontness interaction. Figure 9 illustrates the mean error rates for each fricative contrast pair as a function of front and back vowels. The analysis indicates that only the error rates for /f/ vs. /θ/ and /v/ vs. /ð/ varied as a function of vowel frontness.[3]

The only other significant source is the pair within contrast type. Figure 10 shows the error rates for each contrast pair collapsed over all vowels. Clearly, /f/ vs. /θ/ and /v/ vs. /ð/ show unusually high error rates as compared to the other consonant contrasts. The univariate F tests confirm these two contrasts as significantly different from the others, while no other differences were found to exist within each contrast type. In fact, no other source showed significant effects.

Error data on the fricative contrasts as a function of vowel length and vowel height is worth considering. Figure 11 is a plot of each contrast pair as a function of vowel length, while Figure 12 shows each pair as a function of vowel height. The lack of any differential error rates with regard to these dimensions will be discussed in the following chapter.

[3]The univariate analysis indicates that the /v/ vs. /ð/ x vowel frontness interaction is of borderline significance, $F(1, 35) = 11.03$, $p < .002$. The significance level for this source (pair x frontness) in the univariate analysis is $p < .0016$. However, because this interaction parallels the /f/ vs. /θ/ x frontness interaction, /v/ vs. /ð/ will be discussed as a probable real effect even though it did not quite reach criterion.

TABLE 9

Post Hoc Analysis: Source Table for Univariate

Analysis of Variance Among Significant Multivariate Sources

Source	F	df	Probability
Vowel Frontness	24.25	1,35	< .0001*
Pair Within Contrast Type			
f-θ vs. f-s, θ-s	71.16	1,35	< .0001*
f-s vs. θ-s	.77	1,35	< .38
v-ð vs. v-z, ð-z	76.50	1,35	< .0001*
v-z vs. ð-z	.28	1,35	< .60
f-v vs. θ-ð, s-z	.06	1,35	< .80
θ-ð vs. s-z	.97	1,35	< .33
Pair Within Contrast Type x Frontness			
f-θ x Frontness vs. f-s, θ-s x Frontness	11.90	1,35	.0015*
f-s x Frontness vs. θ-s x Frontness	3.60	1,35	.06
v-ð x Frontness vs. v-z, ð-z x Frontness	11.03	1,35	.002
v-z x Frontness vs. ð-z x Frontness	.23	1,35	.63
f-v x Frontness vs. θ-ð, s-z x Frontness	.39	1,35	.53
θ-ð x Frontness vs. s-z x Frontness	.86	1,35	.35

*Significant at level indicated

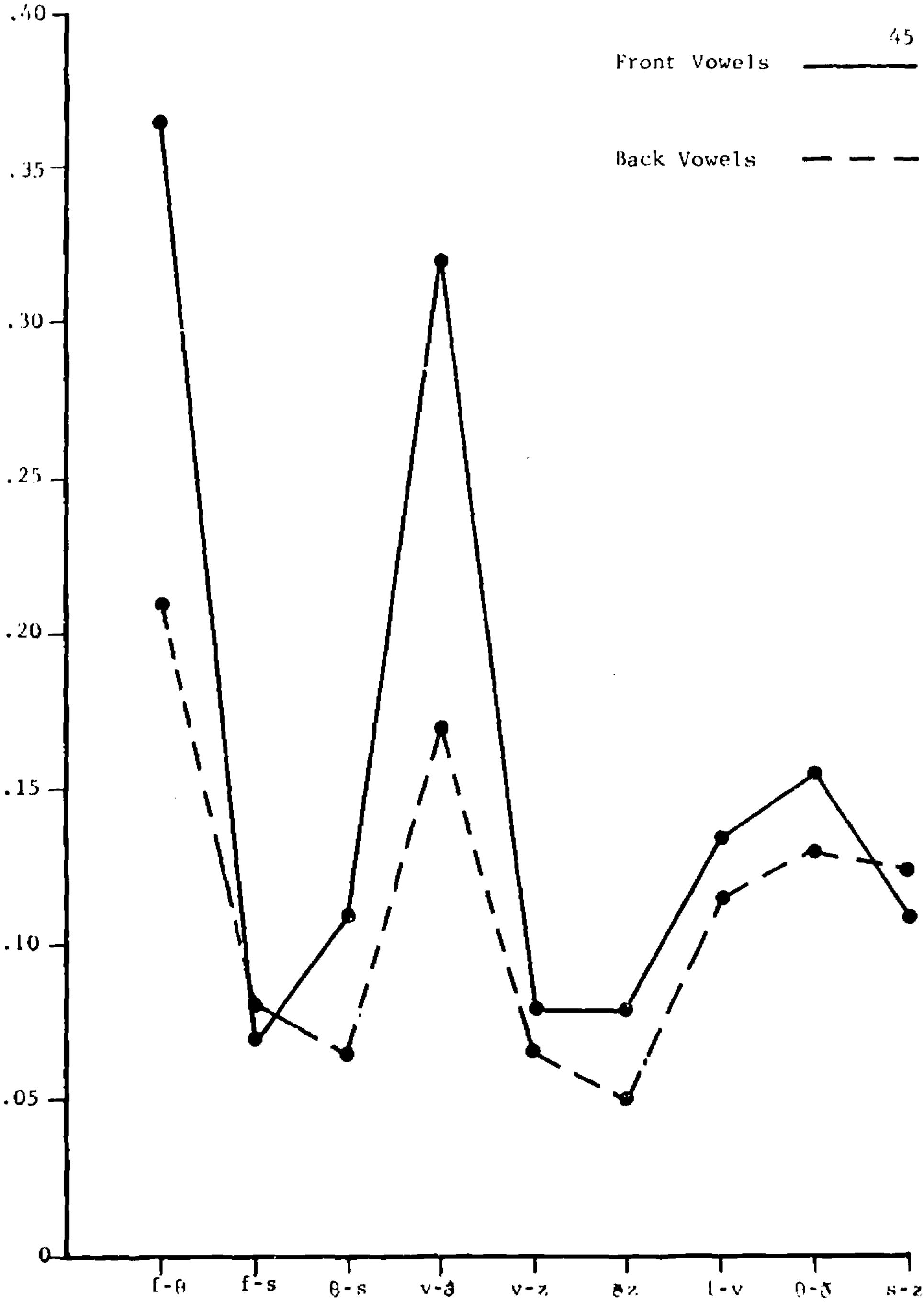

Fig. 9. Mean proportion of errors for 9 fricative consonant contrasts as a function of frontand back vowels.

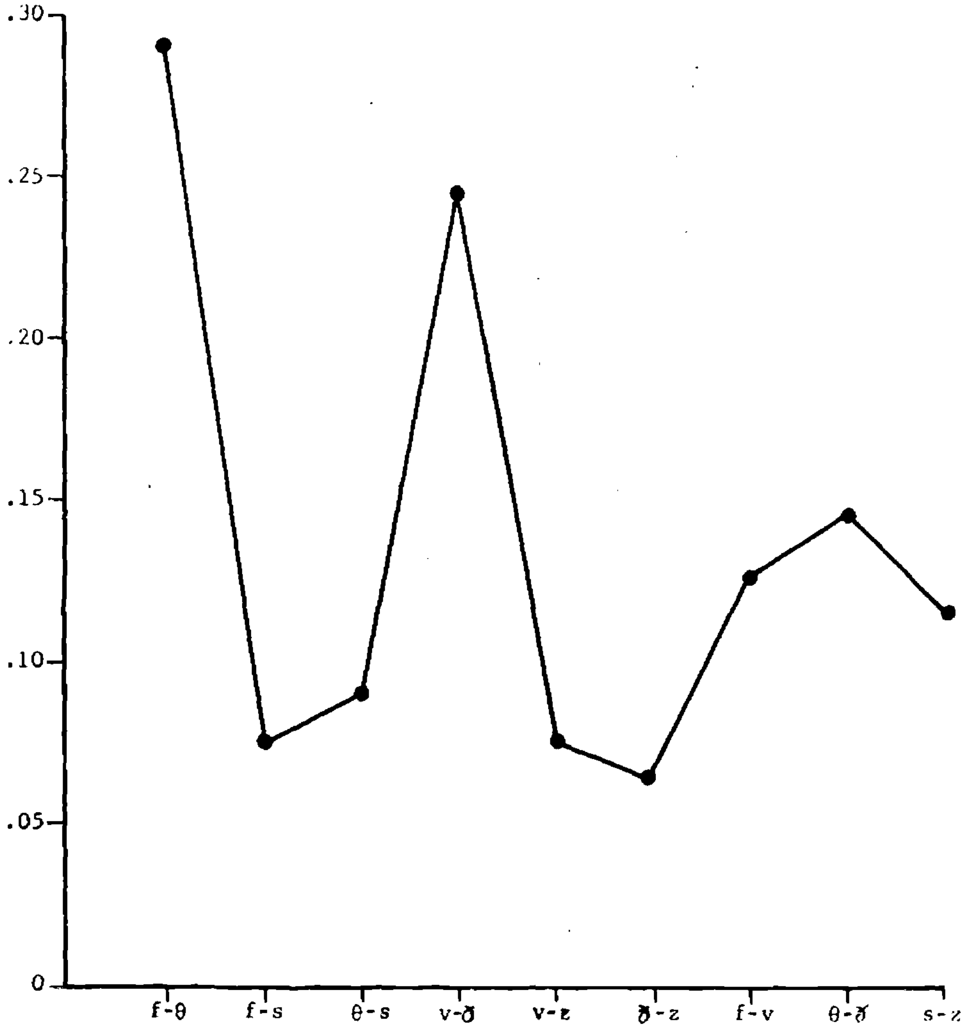

Fig. 10. Mean proportion of errors for 9 fricative consonant contrasts over all vowels.

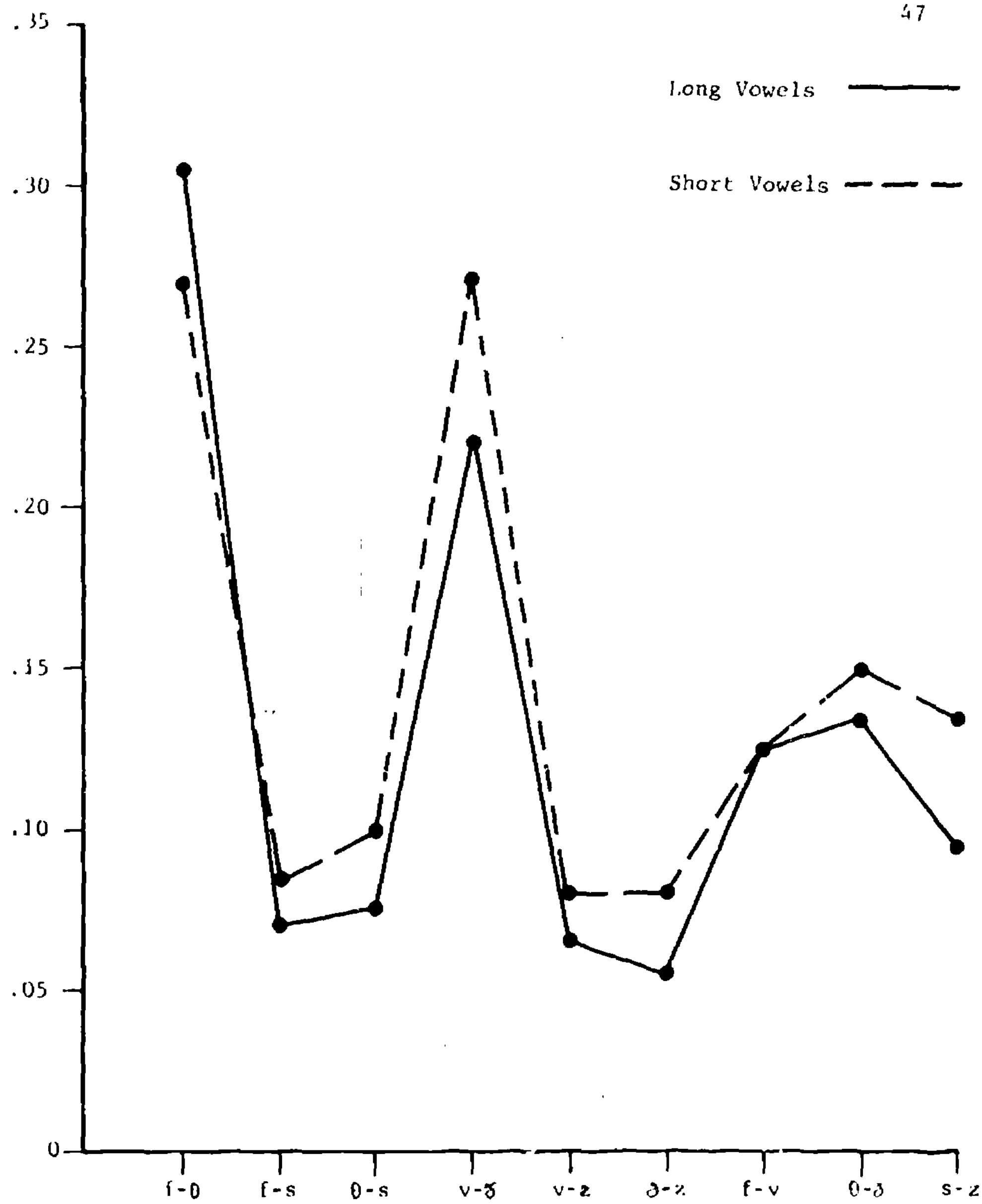

Fig. 11. Mean proportion of errors for 9 fricative consonant contrasts as a function of long and short vowels.

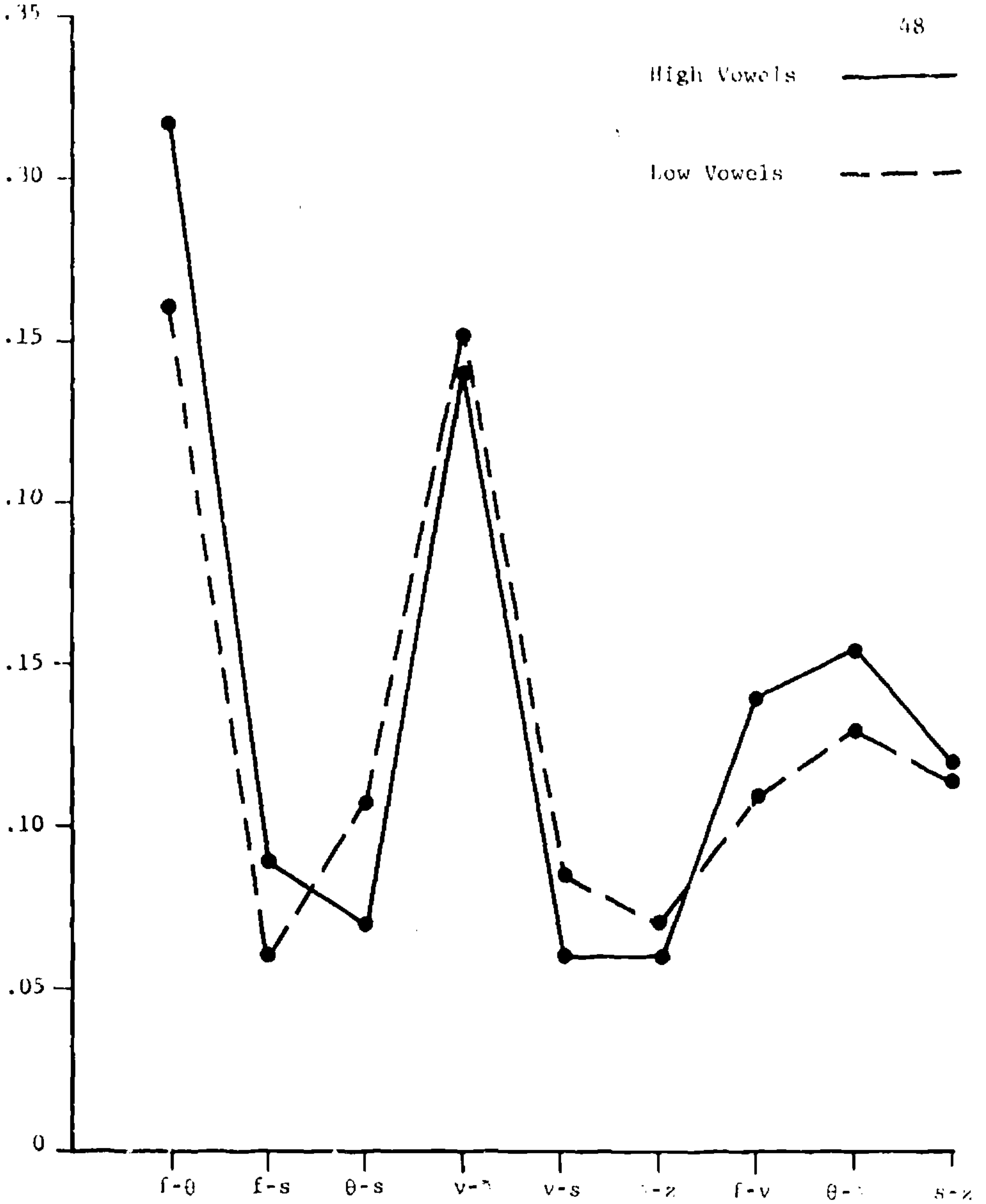

Fig. 12. Mean proportion of errors for 9 fricative consonant contrasts as a function of high and low vowels.

ACOUSTIC MEASURES ON THE STIMULUS TAPES STOP STUDY

In light of the significant effects due to vowel length in the stop study, measures of syllable duration seemed necessary. Since the stimuli consisted of open syllables, the danger of producing vowels whose durations would not conform to predictions found in the literature was present. Thus, an acoustic analysis was performed on the stimulus items. The instrument chosen for this purpose was the Kay Electronic Sound Spectograph (model 601A). From the sonagrams obtained, the duration in milliseconds of each CV syllable was measured, and the mean durations for each group of syllables containing a different vowel were computed. Table 10 presents the mean syllable durations for each vowel context.

TABLE 10

Mean Durations (in milliseconds) for Stimulus Items Presented in the Stop Discrimination Experiment. (Syllable durations are presented according to the vowel in the syllable)

	Long Vowels				Short Vowels			
	i	æ	a	u	ɪ	ɛ	ə	ʊ
Syllable Duration (in milliseconds)	303	353	344	315	243	267	240	256

It should be pointed out that the duration of syllables containing short vowels was consistently less than the long vowel syllable duration regardless of the consonant contrast involved.

To check further that it is indeed the vowel that contributes to longer syllable duration, the duration of the noise portion of the voiceless stop consonants was measured and compared according to short and long vowel environments. Table 11 is a presentation of the mean consonant duration in long and short vowel syllables.

Table 11

Mean Duration (in milliseconds) of the Noise Portion of Voiceless Stop Sounds According to Long and Short Vowel Contexts

Following Vowel	p	t	k
Long Vowel	64.5	80.2	87.0
Short Vowel	64.5	78.0	86.2

The voiceless stops were chosen for two reasons: 1) The boundary between the noise portion and the vocalic portion is easily discernible (see Peterson and Lehiste, 1960) and 2) The vowel length effect appeared strongest among the voiceless place contrasts so that if this effect is in any way related to noise duration, it should be most evident in the case of the voiceless stops.

Fricative Study

Even though there was no effect due to vowel length in the fricative discrimination experiment, it is important to discover whether or not the proposed vowel length differences actually were present in the stimulus productions. Accordingly, sonagram measurements were also made for this set of stimuli. Table 12 shows the mean durations for each group of syllables containing a different vowel. From this it is evident that differentially vowel length was present in the stimulus materials.

Table 12

Mean Durations (in milliseconds) for Stimulus Items Presented in the Fricative Discrimination Experiment. (Syllable durations are presented according to the vowel in the syllable.)

	Long Vowels				Short Vowels			
	i	æ	a	u	ɪ	ɛ	ə	ʊ
Syllable Duration (in milliseconds)	407	449	425	417	360	381	369	366

METHODOLOGICAL ISSUES INVOLVING THE ERROR DATA

Stop Study

In the study involving initial stops, ABA errors exhibited observed means which appeared to be much higher than the means for ABB errors. The mean error rates on ABA and ABB item types are presented in Figure 13. It was decided to test the significance of the ABA vs. ABB errors across the 6 test days.

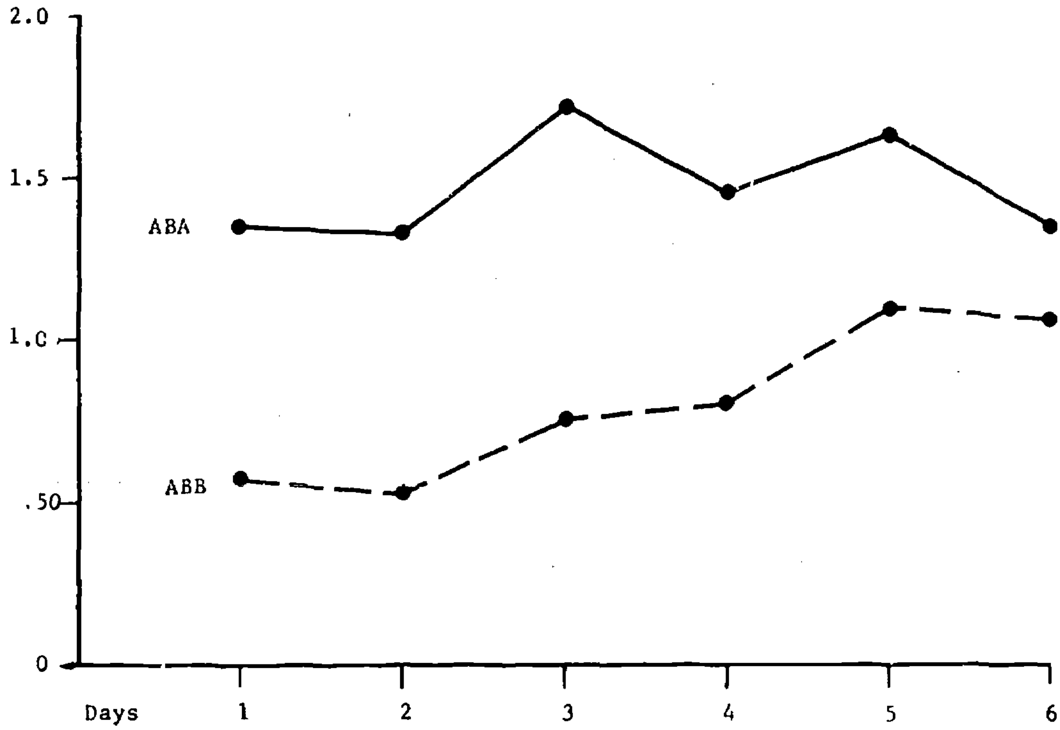

Fig. 13. Mean proportion of errors for ABA and ABB errors plotted over 6 d
of the stop discrimination study.

In addition, since a number of Ss who participated in the present study, had also participated in the pilot study, it seemed possible that the new Ss, those without prior experience in this type of task, were responsible for the ABA-ABB difference, if it existed. Thus, a test of group differences was also included of the 36 Ss who participated in this study, 21 had served in the pilot experiment; these constituted the group with prior experience, while the remaining 15 Ss comprised the group without prior experience.

A 3-factor repeated measures analysis of variance, subjects within groups (2) x days (6) x item type (2) was performed on the error data. Table 13 shows the results of this analysis. Only the item type variable was significant, $F(1, 34) = 5.68$, $p < .02$. Since the days x item type interaction was not significant, it can be concluded that the ABA effect was present over all the 6 test sessions.

Fricative Study

In the fricative study, as in the stop study, ABA errors again appeared to be much higher than ABB errors. In Figure 14, the ABA vs. ABB errors from the fricative study are plotted. It was decided to test the significance of this difference for each of the 6 test days.

A 2-factor repeated measures design, days (6) x item type (2) was performed on the error data. Table 14 presents the results of this analysis. Only the item type variable was significant,

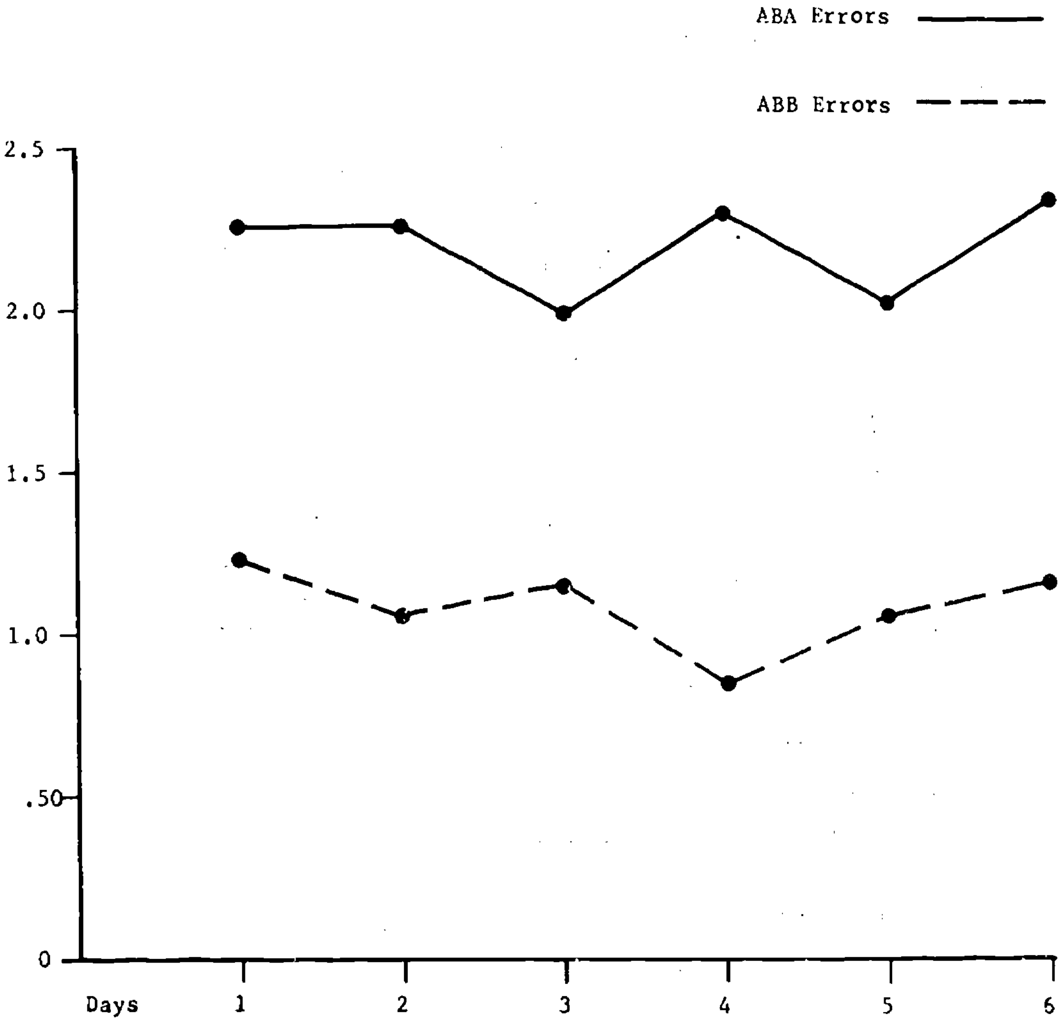

Fig. 14. Mean proportion of errors for ABA and ABB errors plotted over 6 days of the fricative discrimination study.

$F(1, 35) = 17.9$, $p < .0002$. Since the days x item type interaction was not significant, it is apparent that the ABA effect was present for all 6 test sessions.

TABLE 13

Source Table for the Analysis of Variance

for Subjects Within Groups x Days x Item Type

(From the Stop Study)

Source	df	MS	F	Probability
Groups	1	75.2	NS	
Days	5	4.03	NS	
Item Type	1	144	5.68*	<.02
Groups x Days	5	2.45	NS	
Days x Item Type	5	.23	NS	
Groups x Item Type	1	3.4	NS	
Groups x Days x Item Type	5	.034	NS	

*Significant at level indicated

TABLE 14

Source Table for the Analysis of Variance

for Days x Item Type. (From the Fricative Study)

Source	df	MS	F	Probability
Days	5	.85	NS	
Item Type	1	400	17.9*	<.0002
Days x Item Type	5	.59	NS	

*Significant at level indicated

Chapter V

DISCUSSION AND CONCLUSIONS

VOWEL LENGTH

The analysis of the error data showed that varying the vowel context in which two contrasting stops are presented does affect the discrimination probabilities. Subjects in this study discriminated initial stops significantly better in long vowel contexts than in short vowel contexts. It was suggested in Chapter II that the duration of the vocalic portion of a stop-plus-vowel syllable may affect the primary cues by which phonemic decisions are made. It seems a reasonable hypothesis that longer vocalic segments yield longer transition segments, and the transition has been shown to be one of the primary parameters that distinguish one stop from another. This argument is enhanced by the finding that the noise portion of the syllable is of equal duration before long and short vowels.

However, the argument would be further strengthened if the error data had showed the long vowel effect with regard to the /f/ - /θ/ and /v/ - /ð/ contrasts in the fricative study. No differences were found due to vowel length with regard to any of the fricative contrasts.

But no differences were expected among either the place contrasts involving /s/ and /z/ or the homorganic voicing contrasts.

VOWEL FRONTNESS

Performance on /f/ - /θ/, /v/ - /ð/ contrasts was affected by vowel context; subjects showed significantly higher error rates with regard to these contrasts in the context of a front vowel as opposed to a back vowel. Back vowel environments facilitated the discrimination of /f/ from /θ/ and /v/ from /ð/. There are good reasons why this may have occurred, and, again, the transition to the vowel was the important factor involved. If an assessment is made of the characteristics in the acoustic signal that distinguish /f/ from /θ/ in the context of a front vowel, and then a comparison is made with regard to these same characteristics when /f/ and /θ/ are contrasted before a back vowel, an interesting effect emerges: back vowel contexts yeild more differentiated transitions than front vowel contexts. Table 15 shows the nature of the /f/ - transition direction as opposed to the /θ/ - transition direction in the case of each of the eight vowel contexts. These observations were carefully drawn from the sonagrams of the stimulus tapes. Back vowels afford the listener more information about the contrast pair in terms of the direction of the transition.

If the transition patterns are the essential cues that distinguish /f/ from /θ/ (and /v/ from /ð/), then the richness of the information provided by back vowel contexts as compared to front vowel contexts can be extremely valuable. This would indeed be a case where certain vowel contexts emphasized the differences between the members of a contrast pair.

TABLE 15

Observations Concerning the Direction of Transitions From /f/ and /θ/ to Each of the Eight Vowels Employed in the Stimulus Items

		/f/ Transition	/ / Transition
Front Vowel Context	i	Rising	Rising
	ɪ	Rising	Rising
	æ	Rising	Rising
	ɛ	Slightly Rising	Slightly Rising
Back Vowel Context	u	Slightly Rising	Neutral
	U	Neutral	Falling
	a	Rising	Falling
	ə	Slightly Rising	Slightly Falling

VOWEL HEIGHT

Wang and Fillmore (1961) found consonant recognition scores to be higher where the consonants preceded low vowels. They attributed this to the finding that low vowels have intrinsically higher amplitudes and presumably make adjacent consonant cues more audible. In the present study no differences were found in discrimination scores along the vowel height dimension in either the stop or the fricative study. But the present findings are not necessarily at odds with the findings of Wang and Fillmore. It seems reasonable to suggest that since their study involved the identification of syllables presented in noise, audibility played a much more crucial role than in the discrimination task used in the present study, where all stimuli were presented under normal listening conditions.

On the other hand, it was mentioned that Sharf (1967) was unable to support the previous experimental literature which showed that intrinsic vowel amplitude was a function of degree of mouth opening--low vowels, of course, being more open. Thus, it may be that the Wang and Fillmore results are not accounted for by the intrinsic vowel amplitude factor, but by something else related to the signal or the experimental technique which they employed.

SUMMARY OF VOWEL EFFECTS

The optimal phonetic context for discriminating stops is a following long vowel; the optimal phonetic context for discriminating /f/ from /θ/, /v/ from /ð/ is a following back vowel. The factor crucial to optimizing stop discriminations--vowel length--affects the cues associated with each member of the contrast pair equally, while the factor crucial to optimizing /f/ - /θ/ and /v/ - /ð/, discriminations--whether the vowel is front or nonfront--affects the cues associated with each member of the contrast pair differentially, emphasizing the differences between them.

The dichotomy of transition patterning that is shown in Table 15 as a function of front and back vowels does not hold for place contrasts among the stops; thus it is not surprising that the error data on stop place contrasts do not reflect a vowel frontness effect. In addition, there is an important difference between the cues available for making the stop discriminations and those available in the /f/-/ /, /v/-/ / discriminations: the decisions concerning stops can be based on cues from the noise portion of the syllable as well as the transition segment; but in the fricative discriminations at issue, cues from the noise portion are very weak. It is reasonable, then that factors related to the transition assume more importance for these fricative discriminations than for the stop discriminations.

In addition to the labiodental-interdental contrast, the other place contrasts are those where /s/ or /z/ are involved. These contrasts were responded to according to the predictions that were made in Chapter II. It was hypothesized that varying vowel environments would have no bearing on the relative ease of place discriminations involving /s/ or /z/ since the noise portions of these sounds provide such a strong cue in terms of frequency, intensity and duration that information from the vocalic portion of the syllable is almost irrelevant under normal conditions. This view is shared by Harris (1958), and reinforced by several acoustic studies (see e.g., Strevens, 1960; Abbs and Minifie, 1969).

PLACE CONTRASTS AND VOICING CONTRASTS

On the basis of the Miller and Nicely (1955) data, it was predicted that voicing contrast would be easier to discriminate than place contrasts. The mean proportion of errors for all stop and fricative contrasts collapsed over all vowels are presented again in Table 16.

Table 16

Mean Proportion of Errors for 9 Stop Contrasts

And 9 Fricative Contrasts Collapsed Over all Vowels

	Contrast Type								
	1. Voiceless Place			2. Voiced Place			3. Voicing		
Stops	1.p-t	2.p-k	3.t-k	1.b-d	2.b-g	3.d-g	1.p-b	2.t-d	3.k-g
	.095	.086	.109	.097	.092	.093	.092	.081	.112
Fricatives	1.f-θ	2.f-s	3.θ-s	1.v-ð	2.v-z	3.ð-z	1.f-v	2.θ-ð	3.s-z
	.289	.076	.088	.246	.074	.067	.126	.144	.118

The analysis showed no difference among the means for the three stop contrast types and no differences between the pairs within each type; the analysis also showed no difference among the means for the fricative contrast types.[4] Thus the voicing feature that proved to be a more powerful cue than the place cue in the Miller and Nicely identification task did not emerge as a better cue in the present discrimination task. If anything, the voicing contrasts in the fricative study were more difficult than the place contrasts where /s/ and /z/ are involved.

A possible explanation of why Miller and Nicely found fewer confusions with regard to the voicing feature involves differential guessing rates associated with a place confusion as opposed to a

[4] The typically high error rates on /f/-/θ/ and /v/-/ð/ make the analysis by contrast type somewhat problematic. The place contrasts involving /s/ and /z/ appear to be easier than the voicing contrasts, but this could not be tested statistically under the present design. In any case, voicing contrasts are certainly not easier than place contrasts where /s/ and /z/ are involved.

voicing confusion.[5] If a subject, upon hearing a syllable composed of a consonant plus /a/, identified all of the features of the consonant except voicing, that subject had a 50% chance of guessing the item correctly. On the other hand, if the subject had identified all of the features of the consonant except its place of articulation, he had only a 33% chance of guessing correctly, if the consonant were a stop and only a 25% chance of gussing correctly if the consonant were a fricative. This could have been the case in the Miller and Nicely study and may account for fewer confusions with regard to the feature of voicing.

CONCLUSIONS

It has been shown that the modifications induced on the acoustic correlates of initial consonants as a function of vowel context affect consonant discrimination probabilities. This offers support on the perceptual side for those who argue from acoustic data the importance of context in phonemic decision processing. These data confirm that the basis for the phonemic decision is the interaction between the consonant and the vowel. Furthermore, the data support the hypothesis that multiple cues constitute the acoustic correlate of a phoneme. A theory involving one-to-one correspondence between the acoustic segment and the sound perceived would not seem to be able to account for the data presented here.

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[5] This point was brought to my attention by Dr. Robin Chapman.

REFERENCES

Abbs, M. S. & Minifie, F. D. Effect of acoustic cues on perceptual confusions in preschool children. Journal of the Acoustical Society of America, 1969, 46, 1535-1542.

Ainsworth, W. A. Perception of stop consonants in synthetic CV syllables. Language and Speech, 1968, 11, 139-155.

Black, J. W. Natural frequency, duration and intensity of vowels in reading. Journal of Speech and Hearing Disorders, 1949, 14, 216-221.

Bondarko, L. V. The syllable structure of speech and distinctive features of phonemes. Phonetica, 1969, 20, 1-40.

Briere, E. J. Phonological testing reconsidered. Language Learning, 1967, XVII, 163-171.

Bush, C. N. Phonetic Variation and Acoustic Distinctive Features. The Hague: Mouton and Co., 1964.

Cooper, F. S., Delattre, P. C., Liberman, A. M., Borst, J. M. & Gerstman, L. J. Some experiments on the perception of synthetic speech sounds. Journal of the Acoustical Society of America, 1952, 24, 597-606.

Delattre, P. C., Liberman, A. M., & Cooper, F. S. Acoustic loci and transitional cues for consonants. Journal of the Acoustical Society of America, 1955, 27, 769-773.

Delattre, P. C., Liberman, A. M., & Cooper, F. S. Formant transitions and loci as acoustic correlates of place of articulation in american fricatives. Studia Linguistica, 1962, 18, 104-121.

Denes, P. B. & Pinson, E. N. The Speech Chain. Baltimore: Waverly Press, 1963.

Fairbanks, G., House, A. S., & Stevens, E. L. An experimental study of vowel intensities. Journal of the Acoustical Society of America, 1950, 22, 457-459.

REFERENCES (continued)

Finn, J. D. Multivariance--Univariate and multivariate analysis of variance and covariance: A FORTRAN IV program. Version 4. Buffalo: Department of Educational Psychology, State University at Buffalo, June, 1968.

Fischer-Jørgensen, E. Acoustic analysis of stop consonants. Miscellanea Phonetica, 1954, II, 42-59.

Fletcher, H. Speech and Hearing in Communication. New York: D. Van Nostrand Co., Inc., 1953.

Fry, D. B. Perception and recognition in speech. For Roman Jakobson, ed. by M. Halle et al. The Hague: Mouton and Co., 1956, 169-173.

Grimm, W. A. Perception of segments of English-spoken consonant-vowel syllables. Journal of the Acoustical Society of America, 1966, 40, 1454-1461.

Halle, M. Review of Manual of Phonology by C. F. Hockett. Journal of the Acoustical Society of America, 1956, 28, 509-511.

Halle, M., Hughes, G. W., & Radley, J. P. A. Acoustic properties of stop consonants. Journal of the Acoustical Society of America, 1957, 29, 107-116.

Harris, K. S. Cues for the discrimination of American English fricatives in spoken syllables. Language and Speech, 1958, 1, 1-7.

House, A. S. On vowel duration in English. Journal of the Acoustical Society of America, 1961, 33, 1174-1178.

Hughes, G. W. & Halle, M. Spectral properties of fricative consonants. Journal of the Acoustical Society of America, 1956, 28, 303-310.

Jakobson, R. & Halle, M. Fundamentals of Language. The Hague: Mouton and Co., 1956.

Kozhevnikov, V. A. & Chistovich, L. A. Speech: Articulation and Perception, Washington, D. C.: Joint Publications Research Service, 1967.

Lehiste, I. Acoustical characteristica of selected English consonants. International Journal of American Linguistics, 1964, 30, Part IV.

REFERENCES (continued)

Lehiste, I. & Peterson, G. E. Vowel amplitude and phonemic stress in American English. Journal of the Acoustical Society of America, 1959, 31, 428-435.

Lehiste, I. & Peterson, G. E. Transitions, glides, and diphthongs. Journal of the Acoustical Society of America, 1961, 33, 268-277.

Liberman, A. M., Cooper, F. S., Shankweiler, D. P. & Studdert-Kennedy, M. Perception of the speech code. Psychological Review, 1967, 74, 431-461.

Liberman, A. M., Delattre, P. C., & Cooper, F. S. The role of selected stimulus variables in the perception of the unvoiced stop consonants. American Journal of Psychology, 1952, 65, 497-516.

Liberman, A. M., Delattre, P. C., Cooper, F. S., & Gerstman, The role of consonant-vowel transitions in the perception of the stop and nasal consonants. Psychological Monographs, 1954, 68, 1-14.

Lisker, L. & Abramson, A. S. Voice on set time in the production and perception of English stops. Status Report on Speech Research. New York: Haskins Labs., 1965.

Lotz, J. Speech and language. Journal of the Acoustical Society of America, 1950, 22, 712-717.

Lyublinskaya, V. V. Recognition of articulation cues in stop consonants in transition from vowel to consonant. Soviet Physics - Acoustics, 1966, 12, 185-192.

Miller, R. J. Jr. Simulaneous Statistical Inference. New York: McGraw-Hill, 1966.

Miller, G. E. and Nicely, P. A. An analysis of perceptual confusions among some English consonants. Journal of the Acoustical Society of America, 1955, 27, 338-352.

Minifir, F. D., Rudegeair, R. E., Milstein, R. and Vivion, M. Relative perceptual cue strength for voiced stop consonants. (In preparation)

Ohman, S.E.G. Coarticulation of stops with vowels. Quarterly Progress and Status Report. Stockholm, Royal Institute of Technology, Speech Transmission Laboratory, Feb. 1963, 1-8.

REFERENCES (continued)

Ohman, S.E.G. Coarticulation in VCV utterances: Spectographic measurements. Journal of the Acoustical Society of America, 1966, 39, 151-168.

Peterson, G. E. and Lehiste, I. Duration of syllable nuclei in English. Journal of the Acoustical Society of America, 1960. 32, 693-703.

Rudegeair, R. E. and Kamil, M. L. Assessment of phonological skills in children. Technical Report No. 118 of The Wisconsin Research and Development Center for Cognitive Learning, 1970.

Sacia, C. F. and Beck, D. J. The Bell System Technical Journal, 1926, 5, 393-403.

Sharf, D. J. Variation in vowel intensity measurements. Language and Speech, 1966, 9, 250-256.

Sherman, D. The influence of vowels in recognition of adjacent consonants. Journal of Speech and Hearing Disorders. 1952, 17, 198-212.

Slis, I. H. and Cohen, A. On the complex regulating of the voiced-voiceless distinction, I and II. Language and Speech, 1969, 12, 80-102 and 137-155.

Strevens, P. Spectra of fricative noise in human speech. Language and Speech, 1960, 3, 32-49.

Templin, M. A study of sound discrimination ability of elementary school pupils. Journal of Speech Disorders, 1943, 8, 127-132.

Tikofsky, R. S. and McInish, J. R. Consonant discrimination by seven year olds: A pilot study. Psychonomic Science, 1968, 10, 61-62.

Tolhurst, G. C. Audibility of voiceless consonants as a function of intensity. Journal of Speech and Hearing Disorders, 1949, 14, 210-215.

Travis, L. E. and Rasmus, B. The speech sound discrimination ability of cases with functional disorders of articulation. Quarterly Journal of Speech, 1931, 17, 217-226.

Vieregge, W. H. Die akustische struktur der plosivlaut. Forschungsbericht, Bonn: Institut Phonetik, 1966, 3, 48.

Wang, W. S-Y. and Fillmore, C. J. Intrinsic cues and consonant perception. Journal of Speech and Hearing Research, 1961, 4, 130-136.

APPENDIX

Stimulus Items

SET A

List 1			List 2			List 3		
1.	pɪ	bɪ	25.	pu	ku	49.	ti	pi
2.	dæ	bæ	26.	dɪ	bɪ	50.	tʊ	kʊ
3.	kə	gə	27.	ga	da	51.	kæ	gæ
4.	dɛ	bɛ	28.	tɪ	pɪ	52.	gɪ	dɪ
5.	pa	ka	29.	dæ	tæ	53.	gu	ku
6.	kɛ	gɛ	30.	pa	ta	54.	bə	gə
7.	tu	du	31.	pʊ	kʊ	55.	gæ	bæ
8.	kæ	tæ	32.	pu	bu	56.	ba	pa
9.	bɪ	gɪ	33.	dɛ	tɛ	57.	gi	ki
10.	pʊ	bʊ	34.	dæ	gæ	58.	kɛ	pɛ
11.	ki	ti	35.	ki	pi	59.	tu	ku
12.	dʊ	gʊ	36.	bi	gi	60.	tə	də
13.	di	ti	37.	bə	pə	61.	ba	da
14.	ta	da	38.	pæ	tæ	62.	dɪ	tɪ
15.	du	gu	39.	bə	də	63.	də	tə
16.	ba	ga	40.	ka	ga	64.	ta	ka
17.	tu	pu	41.	gʊ	bʊ	65.	bɛ	pɛ
18.	pə	kə	42.	tə	kə	66.	gu	bu
19.	kɪ	tɪ	43.	pi	bi	67.	gi	di
20.	bæ	pæ	44.	gɪ	kɪ	68.	bʊ	dʊ
21.	gə	də	45.	gɛ	bɛ	69.	kɪ	pɪ
22.	pɛ	tɛ	46.	bu	du	70.	tʊ	dʊ
23.	di	bi	47.	gʊ	kʊ	71.	kæ	pæ
24.	tʊ	pʊ	48.	kɛ	tɛ	72.	dɛ	gɛ

SET B

List 1			List 2			List 3		
1.	bu	du	25.	ti	pi	49.	gɛ	dɛ
2.	tæ	dæ	26.	də	gə	50.	pʊ	tʊ
3.	bə	gə	27.	tu	du	51.	dɪ	tɪ
4.	gu	ku	28.	kɛ	gɛ	52.	gʊ	kʊ
5.	pɛ	bɛ	29.	tʊ	kʊ	53.	tɛ	dɛ
6.	pa	ka	30.	kɪ	gɪ	54.	ti	ki
7.	bɪ	gɪ	31.	da	ga	55.	gʊ	bʊ
8.	tɛ	pɛ	32.	kæ	gæ	56.	pa	ta
9.	bʊ	pʊ	33.	tu	ku	57.	də	tə
10.	pi	ki	34.	tæ	pæ	58.	ki	gi
11.	gi	di	35.	gɛ	bɛ	59.	kæ	pæ
12.	da	ba	36.	pi	bi	60.	də	bə
13.	kə	tə	37.	da	ta	61.	ba	pa
14.	pu	tu	38.	bʊ	dʊ	62.	gæ	bæ
15.	kʊ	pʊ	39.	kɛ	pɛ	63.	kɛ	tɛ
16.	ga	ka	40.	gu	bu	64.	ba	ga
17.	di	ti	41.	dɪ	bɪ	65.	di	bi
18.	bɛ	dɛ	42.	bi	gi	66.	ku	pu
19.	kæ	tæ	43.	bə	pə	67.	pə	tə
20.	gə	kə	44.	tʊ	dʊ	68.	pæ	bæ
21.	tɪ	kɪ	45.	bæ	dæ	69.	gɪ	dɪ
22.	gæ	dæ	46.	tɪ	pɪ	70.	bu	pu
23.	pɪ	bɪ	47.	ka	ta	71.	pɪ	kɪ
24.	dʊ	gʊ	48.	pə	kə	72.	du	gu

SET C

List 1			List 2			List 3		
1.	gɪ	bɪ	25.	ga	ka	49.	gɛ	dɛ
2.	bɛ	dɛ	26.	gə	bə	50.	du	bu
3.	ta	pa	27.	tu	pu	51.	dæ	tæ
4.	gæ	kæ	28.	bɛ	gɛ	52.	kə	pə
5.	kɪ	pɪ	29.	pæ	bæ	53.	dɪ	gɪ
6.	dʊ	bʊ	30.	gə	kə	54.	pi	ti
7.	dɛ	tɛ	31.	gʊ	dʊ	55.	da	ba
8.	ga	ba	32.	du	tu	56.	bi	pi
9.	ku	tu	33.	da	pa	57.	ta	ka
10.	də	bə	34.	bɪ	dɪ	58.	gɛ	kɛ
11.	bʊ	pʊ	35.	ki	pi	59.	bæ	dæ
12.	gu	du	36.	pɪ	tɪ	60.	bʊ	gʊ
13.	gi	bi	37.	pɛ	kɛ	61.	di	gi
14.	gæ	dæ	38.	tæ	kæ	62.	pa	ba
15.	bɪ	pɪ	39.	bu	gu	63.	dʊ	tʊ
16.	ki	ti	40.	kʊ	tʊ	64.	pɛ	tɛ
17.	ku	gu	41.	tɪ	dɪ	65.	də	gə
18.	tə	pə	42.	pɛ	bɛ	66.	kɪ	tɪ
19.	tɛ	kɛ	43.	da	ga	67.	pʊ	kʊ
20.	pə	bə	44.	tə	kə	68.	pæ	tæ
21.	pæ	kæ	45.	ti	di	69.	pu	ku
22.	ta	da	46.	bæ	gæ	70.	kɪ	gɪ
23.	tʊ	pʊ	47.	bi	di	71.	tə	də
24.	ki	gi	48.	kʊ	gʊ	72.	bu	pu

SET D

List 1			List 2			List 3		
1.	bu	gu	25.	pɪ	tɪ	49.	ka	pa
2.	gʊ	dʊ	26.	dɛ	bɛ	50.	gɛ	kɛ
3.	pu	tu	27.	ku	pu	51.	pə	bə
4.	bɛ	gɛ	28.	ga	da	52.	kʊ	tʊ
5.	bi	di	29.	bɪ	pɪ	53.	ga	ba
6.	tæ	pæ	30.	gi	bi	54.	dɛ	gɛ
7.	pi	ki	31.	tɛ	kɛ	55.	tæ	kæ
8.	kə	gə	32.	tθ	pə	56.	di	gi
9.	ba	da	33.	dʊ	bʊ	57.	tɛ	pɛ
10.	gɪ	bɪ	34.	gə	bə	58.	bʊ	gʊ
11.	kʊ	gʊ	35.	ka	ga	59.	gi	ki
12.	pɛ	kɛ	36.	kɪ	gɪ	60.	du	bu
13.	bi	pi	37.	ka	ta	61.	bæ	pæ
14.	tæ	dæ	38.	dθ	tθ	62.	da	ta
15.	dʊ	pʊ	39.	ti	ki	63.	pi	ti
16.	ta	pa	40.	gæ	kæ	64.	bɪ	dɪ
17.	dæ	gæ	41.	pʊ	tʊ	65.	dʊ	tʊ
18.	ku	gu	42.	pæ	kæ	66.	gə	də
19.	tɪ	dɪ	43.	bɛ	pɛ	67.	gɪ	kɪ
20.	pa	ba	44.	gu	du	68.	kθ	pə
21.	tɪ	kɪ	45.	pʊ	bʊ	69.	bæ	gæ
22.	bθ	də	46.	du	tʊ	70.	pu	bu
23.	tɛ	dɛ	47.	dæ	bæ	71.	pɪ	kɪ
24.	kθ	tθ	48.	ti	di	72.	ku	tu

SET A

List 1			List 2			List 3		
1.	fɪ	vɪ	25.	fu	su	49.	θi	fi
2.	ðæ	væ	26.	ðɪ	vɪ	50.	θʊ	sʊ
3.	sə	zə	27.	za	ða	51.	sæ	zæ
4.	ðɛ	vɛ	28.	θɪ	fɪ	52.	zɪ	ðɪ
5.	fa	sa	29.	ðæ	θæ	53.	zu	su
6.	sɛ	zɛ	30.	fa	θa	54.	və	zə
7.	θu	ðu	31.	fʊ	sʊ	55.	zæ	væ
8.	sæ	θæ	32.	fu	vu	56.	va	fa
9.	vɪ	zɪ	33.	ðɛ	θɛ	57.	zi	si
10.	fʊ	vʊ	34.	ðæ	zæ	58.	sɛ	fɛ
11.	si	θi	35.	si	fi	59.	θu	su
12.	ðʊ	zʊ	36.	vi	zi	60.	θə	ðə
13.	ði	θi	37.	və	fə	61.	va	ða
14.	θa	ða	38.	fæ	θæ	62.	ðɪ	θɪ
15.	ðu	zu	39.	və	ðə	63.	fə	θə
16.	va	za	40.	sa	za	64.	θa	sa
17.	θu	fu	41.	zʊ	vʊ	65.	vɛ	fɛ
18.	fə	sə	42.	θə	sə	66.	zu	vu
19.	sɪ	θɪ	43.	fi	vi	67.	zi	ði
20.	væ	fæ	44.	zɪ	sɪ	68.	vʊ	ðʊ
21.	zə	ðə	45.	zɛ	vɛ	69.	sɪ	fɪ
22.	fɛ	θɛ	46.	vu	ðu	70.	θʊ	ðʊ
23.	ði	vi	47.	zʊ	sʊ	71.	sæ	fæ
24.	θʊ	fʊ	48.	sɛ	θɛ	72.	ðɛ	zɛ

SET B

List 1			List 2			List 3		
1.	vu	ðu	25.	θi	fi	49.	zɛ	ðɛ
2.	θæ	ðæ	26.	ðə	zə	50.	fʊ	θʊ
3.	və	zə	27.	θu	ðu	51.	ðɪ	θɪ
4.	zu	su	28.	sɛ	zɛ	52.	zʊ	sʊ
5.	fɛ	vɛ	29.	θʊ	sʊ	53.	θɛ	ðɛ
6.	fa	sa	30.	sɪ	zɪ	54.	θi	si
7.	vɪ	zɪ	31.	ða	za	55.	zʊ	vʊ
8.	θɛ	fɛ	32.	sæ	zæ	56.	fa	θa
9.	vʊ	fʊ	33.	θu	su	57.	ðə	θə
10.	fi	si	34.	θæ	fæ	58.	si	zi
11.	zi	ði	35.	zɛ	vɛ	59.	sæ	fæ
12.	ða	va	36.	fi	vi	60.	ðə	və
13.	sə	θə	37.	ða	θa	61.	va	fa
14.	fu	θu	38.	vʊ	ðʊ	62.	zæ	væ
15.	sʊ	fʊ	39.	sɛ	fɛ	63.	sɛ	θɛ
16.	za	sa	40.	zu	vu	64.	va	za
17.	ði	θi	41.	ðɪ	vɪ	65.	ði	vi
18.	vɛ	ðɛ	42.	vi	zi	66.	su	fu
19.	sæ	θæ	43.	və	fə	67.	fə	θə
20.	zə	sə	44.	θʊ	ðʊ	68.	fæ	væ
21.	θɪ	sɪ	45.	væ	ðæ	69.	zɪ	ðɪ
22.	zæ	ðæ	46.	θɪ	fɪ	70.	vu	fu
23.	fɪ	vɪ	47.	sa	θa	71.	fɪ	sɪ
24.	ðʊ	zʊ	48.	fə	sə	72.	ðu	zu

SET C

List 1			List 2			List 3		
1.	zɪ	vɪ	25.	za	sa	49.	zε	ðε
2.	vε	ðε	26.	zə	və	50.	ðu	vu
3.	θa	fa	27.	θu	fu	51.	ðæ	θæ
4.	zæ	sæ	28.	vε	zε	52.	sə	fə
5.	sɪ	fɪ	29.	fæ	væ	53.	ðɪ	zɪ
6.	ðʊ	vʊ	30.	zə	sə	54.	fi	θi
7.	ðε	θε	31.	zu	ðʊ	55.	ða	va
8.	za	va	32.	ðu	θu	56.	vi	fi
9.	su	θu	33.	sa	fa	57.	θa	sa
10.	ðə	və	34.	vɪ	ðɪ	58.	zε	sε
11.	vʊ	fʊ	35.	si	fi	59.	væ	ðæ
12.	zu	u	36.	fɪ	θɪ	60.	vʊ	zʊ
13.	zi	vi	37.	fε	sε	61.	ði	zi
14.	zæ	ðæ	38.	θæ	æ	62.	fa	va
15.	vɪ	fɪ	39.	vu	zu	63.	ðʊ	θʊ
16.	si	θi	40.	sʊ	θʊ	64.	fε	θε
17.	su	zu	41.	θɪ	ðɪ	65.	ðə	zə
18.	θə	fə	42.	fε	vε	66.	sɪ	θɪ
19.	θε	sε	43.	ða	za	67.	fʊ	sʊ
20.	fə	və	44.	θə	sə	68.	fæ	θæ
21.	fæ	sæ	45.	θi	θi	69.	fu	su
22.	θa	ða	46.	væ	zæ	70.	sɪ	zɪ
23.	θʊ	fʊʊ	47.	vi	ði	71.	θə	ðə
24.	si	zi	48.	sʊ	zʊ	72.	vu	fu

SET D

List 1			List 2			List 3		
1.	vu	zu	25.	fɪ	θɪ	49.	sa	fa
2.	zʊ	ðʊ	26.	ðɛ	vɛ	50.	zɛ	sɛ
3.	fu	θu	27.	su	fu	51.	fə	və
4.	vɛ	zɛ	28.	za	ða	52.	sʊ	θʊ
5.	vi	ði	29.	vɪ	fɪ	53.	za	va
6.	θæ	fæ	30.	zi	vi	54.	ðɛ	zɛ
7.	fi	si	31.	θɛ	sɛ	55.	θæ	xæ
8.	sə	zə	32.	θə	fə	56.	ði	zi
9.	va	ða	33.	ðʊ	vʊ	57.	θɛ	fɛ
10.	zɪ	vɪ	34.	zə	və	58.	vʊ	zʊ
11.	sʊ	zʊ	35.	sa	za	59.	zi	si
12.	fɛ	sɛ	36.	ðɪ	zɪ	60.	ðu	vu
13.	vi	fi	37.	sa	θa	61.	væ	fæ
14.	θæ	ðæ	38.	ðə	θə	62.	ða	θa
15.	sʊ	fʊ	39.	θi	si	63.	fi	θi
16.	θa	fa	40.	zæ	sæ	64.	vɪ	ðɪ
17.	ðæ	zæ	41.	fʊ	θʊ	65.	ðʊ	θʊ
18.	su	zu	42.	fæ	sæ	66.	zə	ðə
19.	θɪ	ðɪ	43.	vɛ	fɛ	67.	zɪ	sɪ
20.	fa	va	44.	zu	ðu	68.	sə	fə
21.	θɪ	sɪ	45.	fʊ	vʊ	69.	væ	zæ
22.	və	ðə	46.	ðu	θu	70.	fu	vu
23.	θɛ	ðɛ	47.	ðæ	væ	71.	fɪ	sɪ
24.	sə	θə	48.	θi	ði	72.	su	θu